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REPORT

SLOPE STABILITY STUDY FOR RAJMAHAL OCP

GODDA JHARKHAND

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By

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1.0 PROJECT PROFILE

1.1 Introduction

Project Report for Rajmahal opencast was originally sanctioned in August, 1980 for a rated capacity of 5.0 MTY. The project was subsequently expanded to a rated capacity of 10.5 MTY. The Projection Report for Rajmahal Expansion OCP(10.5 Mty to 17 Mty) has been prepared based on the projection parameter of the Expansion projection for 17 Mty.

1.2 Scope of the work

Scientific study of Dahenangi Patch for

a). Dump Slope Stability analysis of failed dump mass upto the hard benches
b). Slope stability of dump Slope

1.3 Geology and hydrogeology

Rajmahal OCP lies within Lalmatia Exploration Block which covers an area of 15 Sq.Km. and has been explored by CMPDI. The geological report of the block was published in march 1984 considering the data from 200 boreholes. This geological report forms the basis of the approved PR of 10.5 MTY capacity.

Altogether eight persistent coal horizons of Barakar formation have been identified in the block. The seams, from bottom upwards are seams I, II (bot), (Top), III, IV,IX,X & XI. More than 95% of the reserves in the block occurs in the seams II (bot), II(top) and III along with their various combinations.

1.3.1 Regional Geology

The Rajmahal coalfields consists of a series of lower Gondwana exposures aligned roughly in the N-S direction along the foot of the Rajmahal hills. The Barakars have been identified to lying with a depositional contact on the Archeans which lie towards west. In addition to these lithostratigraphic units, Talchir (underlying the Barakars) and Dubrajpurs (underlying the Rajmahal traps) have also been found exposed in parts of these coalfields.

1.3.2 Geology of the Block

The Lalmatia block from the northern most part of Hura coal prospect. The general stratigraphic sequence within the block is as follows.

Table 1 : Stratigraphic sequence of Lalmatia Block

Group	Formation	Lithology	Thickness Range(m)
Recent to Sub-recent	Alluvium	UNCONFORMITY	0-15
Upper Gondwana	Rajmahal Traps	Rajmahal volcanic and inter-trappean sandstone and shales. UNCONFORMITY	50
Lower Gondwana	Barakar	Coarse to medium grained sandstone with shale and coal	25-350
		Coarse arkosic sandstone, pebbly at places	15-`50
	Talchirs	Sandstones and shales	10-20
		UNCONFORMITY	
		Granite gneisses, hornblende Schists and pegmaties	

17 normal faults have been postulated within the block. Among these, five southward heading faults, namely Faults F1,5,8,11, and 15 are of major magnitude. As borne out of the interpretation, the southern half of the block appears to be structurally more complex.

1.3.4 Hydrogeology

Five aquifer horizons have been identified in the block as per the hydro-geological investigation conducted in the Lalmatia block by CMPDI. Five major aquifer systems were identified as follows.

Table 2 : Major aquifer system in Rajmahal project

Aquifer Disposition				
Sl. No	Aquifer	Lithology	Confining beds	Nature of Aquifer
1	Water table Aquifer	Clay slit and sand		Unconfined
2	Aquifer-III	Sandstone	Top clay and seam-III	Confined to Semi-confined

3	Aquifer-IIA	Sandstone	Seam-III and Seam-II(top)	confined
4	Aquifer-II	Sandstone	Seam-II(top) and seam-II(bot)	confined
5	Aquifer-IA	Sandstone	Seam-II (bot) and seam-I	confined
6	Aquifer-I	Sandstone		confined

1.3.5 Climate

The area is characterized with mild to moderate, tropical to sub-tropical climate, with cold winters and fairly hot and dry summers. During pre-monsoon, light rain is noticed and during monsoon 80% of annual rail fall occurs and weather is cooler due to rains. The mean of maximum temperature is 30.70^{0}C and mean of minimum temperature is 18.92^0 C and the average of the maximum and minimum is 22.8^{0}C.

1.4 Location

Rajmahal opencast mine, under the administrative control of ECL is located in the Godda district of Jharkhand. It lies between latitude 24^0 1" 12' N and 250 03" 15' N and longitudes 87^0 25" 0' E and 87^0 24" 52' E. the site of Rajmahal Opencast mine is accessible by road from Suri (120 km. to the south) or from Sahibganj (50 km. to the North-East). Its nearest railway station is at pirpainti approximately 32 km. North of the area.

1.5 Mining System

The proposed mining system envisaged deployment of shovel-dumper combination for both coal production and OB removal. The thick (15m-35m) mantle of alluvium cover and weathered mantle and above the coal seams which has been called as consolidated OB. The Project Report has been proposed to be worked by 20 m^3 long reach Rope Shovels in conjunction with 170T Dumpers. A thickness of up to 20m of the unconsolidated OB was envisaged to be excavated by 20m^3 long reach Rope Shovels standing on the hard floor. The balance waste material in the form of parting and bands was proposed to be removed by 12m^3 Hydraulic shovel in conjunction with 85T Dumpers. For coal production, 10m^3 Rope shovels and 12m^3 Hydraulic shovels were proposed with 85T dumpers.

1.6 Mine Boundary

As per the approved PR the mine area has been delineated within a maximum OB: Coal thickness ratio of 3.4 :1 at the floor of seam-II (bot) so as to restrict the operations within a maximum stripping ratio of 2m^3/t. This has resulted in the exclusion of the following seams/areas.

(a) Seam-I in the central part of the deposit where it is developed with a thickness of 2m to 6m below a parting of 13m to 34m with the overlying seam-II.

(b) Northern and eastern part of the block and

(c) Most of the coal under Lalmatia hill (68m-104m high)

The mining block as delineated in the approved P.R was grouped into three areas, namely (I) initial mine area which includes the incrop Zone (ii) the main mine area and (iii) the deep mine area generally bounded by fault F_2 and F_{15}. The deep mine area was also excluded from the 25 year mine plan due to the deep seated highly faulted coal seams rendering them difficult to mine.

1.7 Reserves & Stripping Ratio

The geological reserves of the approved P.R as estimated by M.Ss. METCHEM was 493.04 Mt including a reserve of 97.22 Mt in the deep mine area. Out of the above mineable reserves, 240.10 Mt was proposed to be exploited up to 25th year of the OCP with an average stripping ratio of 1.57 m^3/t(for the first 25 years).

2.0 METHODOLOGY OF THE STUDY

The stability analysis was done by finite element method and Limit equilibrium method. These methods have been used to assess the failure mechanisms and to determine the factor of safety. These techniques are widely used to perform stability analysis where the conditions are complex. Modeling has advantages that design ideas can be tested, different material properties can be evaluated and risk analysis can be carried out.

2.1 Geotechnical Assessment of Dump Material

The mine is being worked by shovel-dumper combination. The stability of the slope primarily depends on the strength properties of the dump material, orientation and geology of the dump foundation, infiltration of the rainfall, drainage and groundwater condition within the slope.

The Factor of safety of 1.5 has been considered for long term stability of the dump slope. The angle of repose was considered to be 37°. The stability analyses were done to determine the safe dump slope configuration.

Table 3 shows the material properties used for simulation of dump slope of Rajmahal Overburden. The data is obtained by testing in the laboratory investigation and literature survey.

Table 3: Geotechnical properties of dump and [illegible]

Properties / Type of Material	Cohesion (kPa)	Friction angle (degree)	Modulus of Elasticiy (MPa)	Poisson Ratio	Density gm/cc
Overburden (Re-handle dump)	46	31	800	0.32	2.1
Overburden	36	31	400	0.33	1.8
Insitu rock	1000	30	2000	0.28	2.4

2.2 Limit Equilibrium Method

The conventional limit equilibrium method is used in many geotechnical practices to investigate the equilibrium condition and analyse the stability of slope with varying geotechnical data and geometry. The most common methods for limit equilibrium analysis are methods of slices. The soil mass above the assumed slip surface is divided into vertical slices for purpose of analysis. Several different methods of slices are available for analyzing the circular and non-circular failure condition.

In the present study limit equilibrium method has been used to compute the factor of safety using bishop method. The critical slip surface has been calculated by above methods having the lowest factor of safety. Two-dimensional (2-D) cross section with plane strain conditions has been considered for present analysis.

2.3 Numerical Modeling (Finite Element Method)

The Numerical modeling is widely used to compute stresses and displacements in structures caused by applied load. The method is particularly useful for complex problems. The stability of a slope cannot be determined directly from finite element analyses, but the computed stresses in a slope can be used to compute a factor of safety. PHASES2 based on finite element method has been used to calculate the factor of safety by shear strength reduction technique.

The shear strength reduction technique has two advantages over the conventional approach. The critical failure surface is found automatically and it is not necessary to specify the shape of the failure surface. To perform slope stability analysis with the shear strength reduction technique, simulations are run for a series of increasing trial factor of safety, F^{trial}(Griffiths and Lane, 1999). The actual shear strength properties cohesion (c) and internal friction angle (Φ) are reduced for each trial according to the equations 1 and 2. If the multiple materials are present, the reduction is made simultaneously for all materials. The trial factor of safety is gradually increased until the slope fails. At failure, the safety factor equals the trial safety factor. The factor of safety is defined according to the equation

$$C^{trial} = \frac{1}{F^{trial}} C \qquad ......(1)$$

$$\phi^{trial} = \arctan\left(\frac{1}{F^{trial}} \tan \phi \right) \qquad ......(2)$$

The numerical model of slope has been developed based on finite element method and finite difference method. The key success of numerical modeling is to consider the representative constitutive behaviour of dump material. It has been observed from the literature that dump (soil) behaves as a non-associated elasto-perfectly plastic material. Generally, it obeys Mohr-Coulomb yield function. It can be expressed as:

$$\sigma_1 = 2C\left(\frac{\cos(\phi)}{1-\sin(\phi)}\right) + \sigma_3\left(\frac{1+\sin(\phi)}{1-\sin(\phi)}\right)$$

Where, C and Φ are cohesion and internal frictional angle

σ_1 and σ_3 are principal stress

The factor of safety generally used is in the range of 1.2–1.5 for open pit mines. This factor of safety could either be directly calculated based on limit equilibrium method or indirectly by numerical modeling based on strength reduction technique. The factor of safety must be greater than 1 for stable slope. Due to uncertainties involved in determining the properties of material, leaving some of the parameters in simulation for simplification and presence of some external factors that are not considered for simulation, it is advisable to have minimum factor of safety of slope as 1.5. Keeping the above discussion in mind, Factor of Safety of 1.2 to 1.5 is considered as short term stability and Factor of Safety of 1.5 and above are considered for long term stability.

3.0 STABILITY ANALYSIS

Figure 1 shows the layout of Rajmahal Opencast Coal Mines. The Sections along the mine dump have been taken in consultation with mine officials for simulation of dump slope stability. Finite Element method and limit equilibrium methods are used to assess the stability of slope.

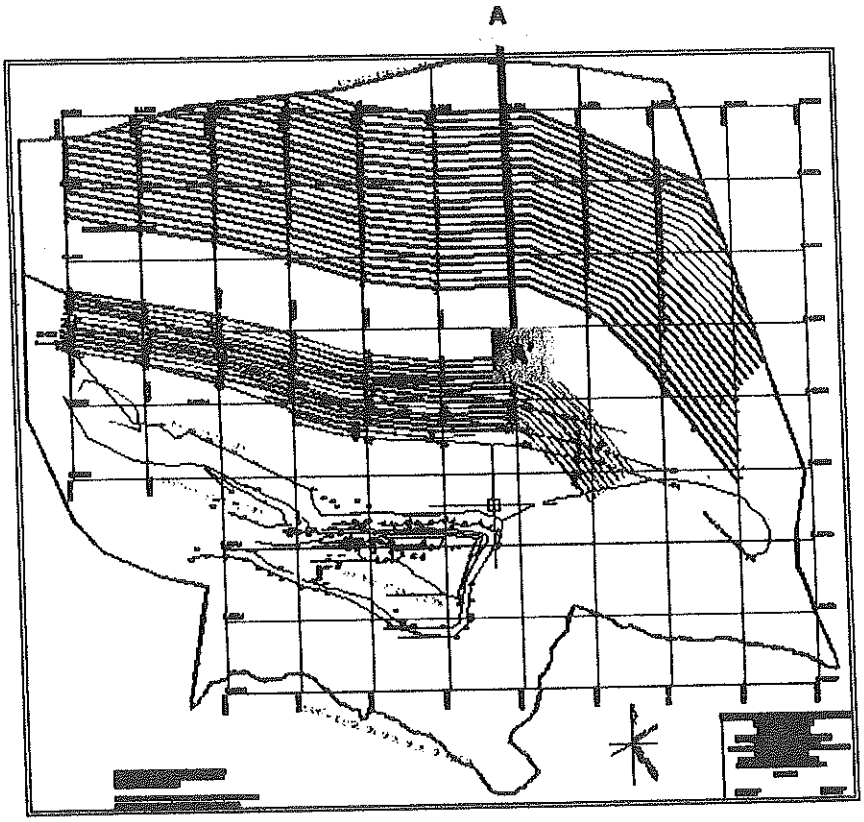


Figure 1: Surface Plan of the mine area

Slope stability of dump in re-handling area

The overburden was dumped over an area. The height of this dump is 120m with 30m bench height and 30m bench width. There was major failure occurred in the above mentioned overburden dump. It has been recommended by scientific investigation carried out earlier that the height of dump must be reduced for the stability point of view. Therefore, overburden is being re-handled to comply with recommendation of scientific investigation. The working and extraction in the above dump is termed as rehandling dump area. The angle of dump repose of material is 37^0. However, as the dump material is consolidated with time, the angle of individual benches can rest on more than the angle of repose. In the study the bench angle is considered to be 56^0.

Simulation of existing mine condition

Figure 2 shows the layout of Rajmahal Opencast Coal Mines. Two Sections have been taken to simulation the intermediate slope benches conditions of Rajmahal OCP. The location of section is show in figure 2 and discretized view is shown in figure 3.

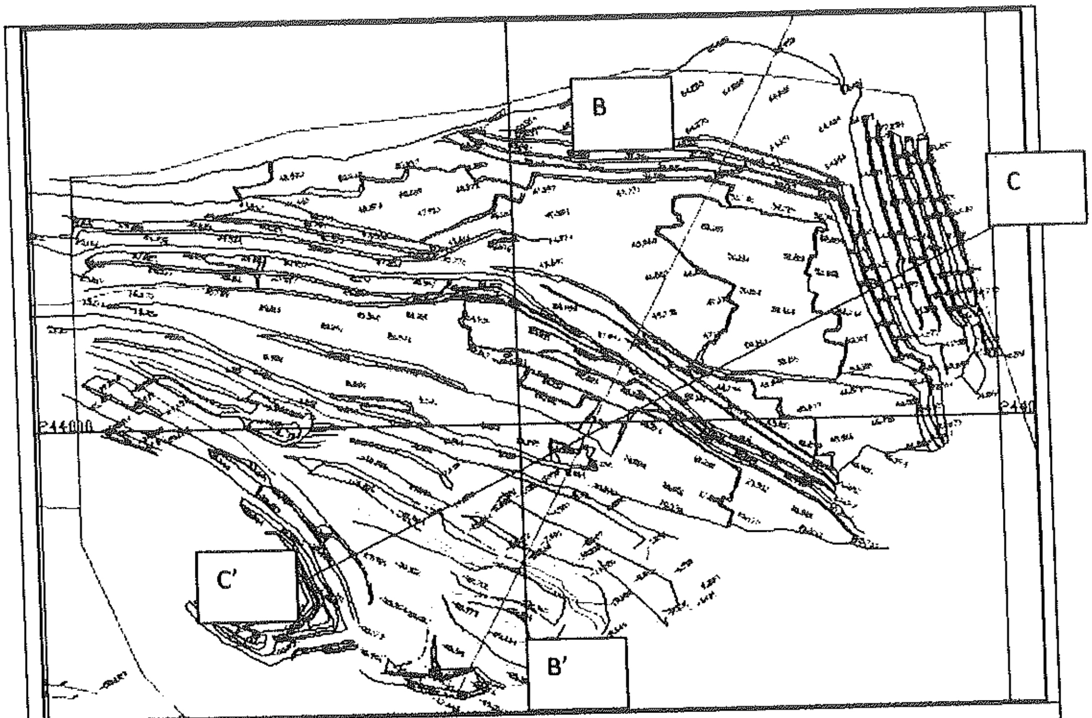
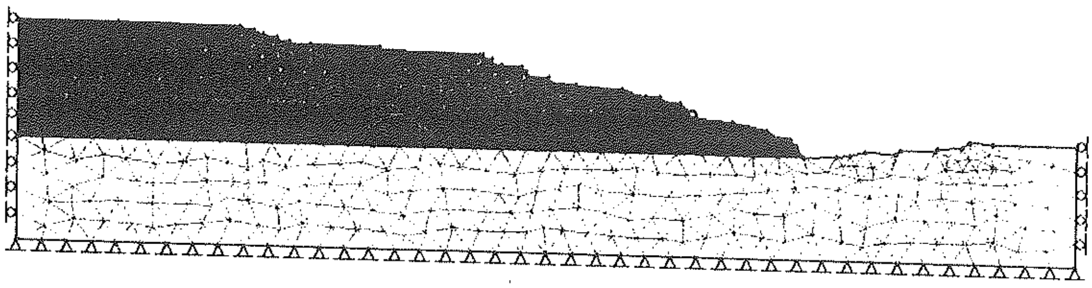
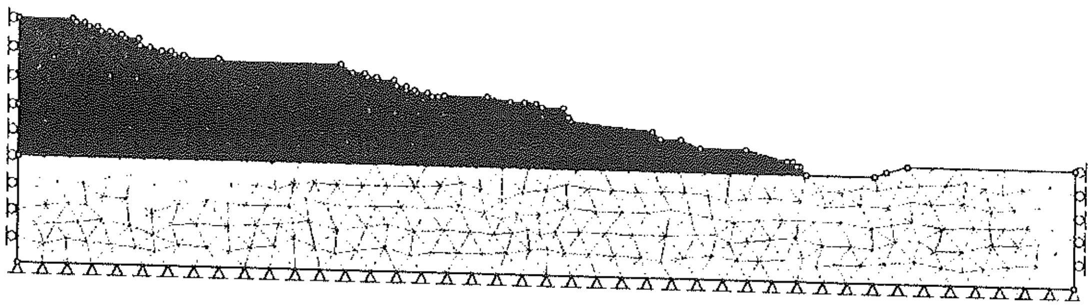


Figure 2: Surface Plan of the mine area

The result in term of factor of safety and shear strain is plotted in figure 4. The factor of safety has been obtained by numerical modeling is 3.06 and 1.99 for section BB' and CC' respectively. It indicates that the slope is stable for long term. The factors of safety has been determined by limit equilibrium are 1.782 and 1.81 for section BB' and CC' respectively (figure 5). It also indicate that the dump slope is stable.

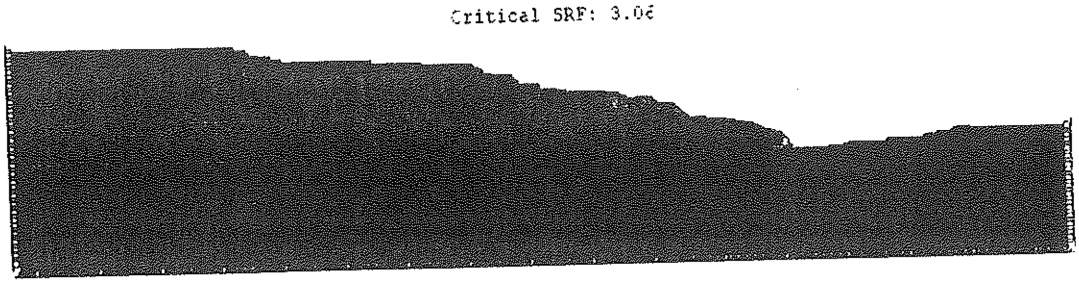


Section B-B'

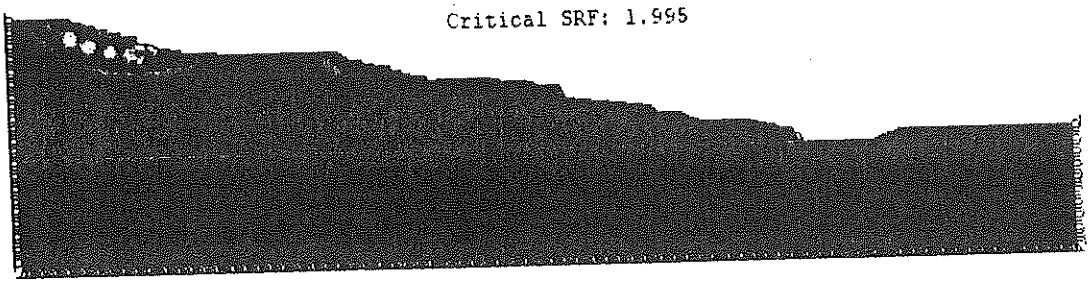


Section C-C'

Figure 3 : Descritized view of dump slope of re-handling dump of intermediate conditions

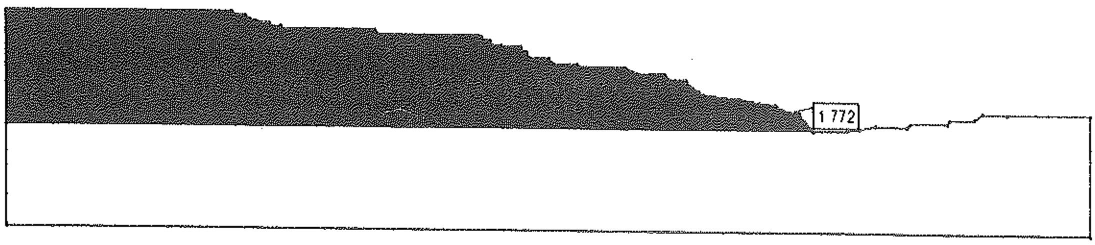


Section B-B'

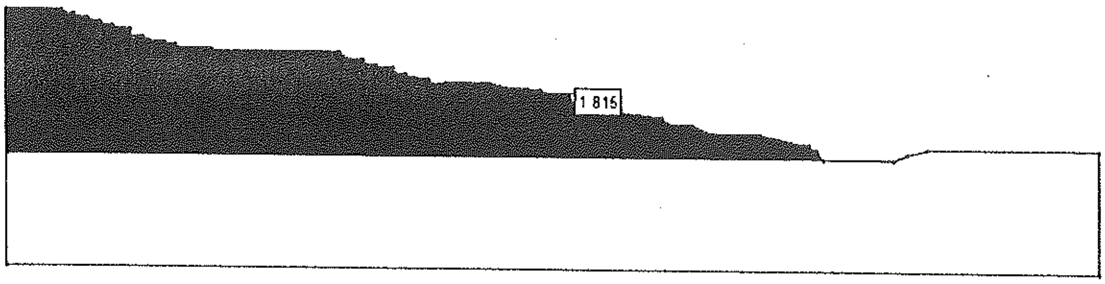


Section C-C'

Figure 4 : Maximum Shear strain with factor of safet of re-handling dump of intermediate conditions by finite element method



Section B-B'



Section C-C'

Figure 5 : Maximum Shear strain with factor of safety of re-handling dump of intermediate conditions using limit equilibrium method.

Simulation of Final Benches of re-handled area

The design of mine benches and slope profile has been collected from the mine officials. The section has been taken for the detailed study for stability of dump (Section AA'). The individual bench slope is 56^0, height 3m and width 9m. The overall height of rehandling area is 125m and overall slope angle is 15^0. The simulations have been done with the help of finite element method and limit equilibrium method.

Material properties have assigned to the model as given in table 3. The complete model is divided into two parts i.e. dump material, insitu rock. The discretized view final dump slope is shown in figure 6. The result in terms of factor of safety and maximum shear strain has been plotted in Figure 7. The factor of safety of the dump slope is 1.98 and 2.41 from finite element and limit equilibrium method respectively. It indicates that the slopes are stable in long term.

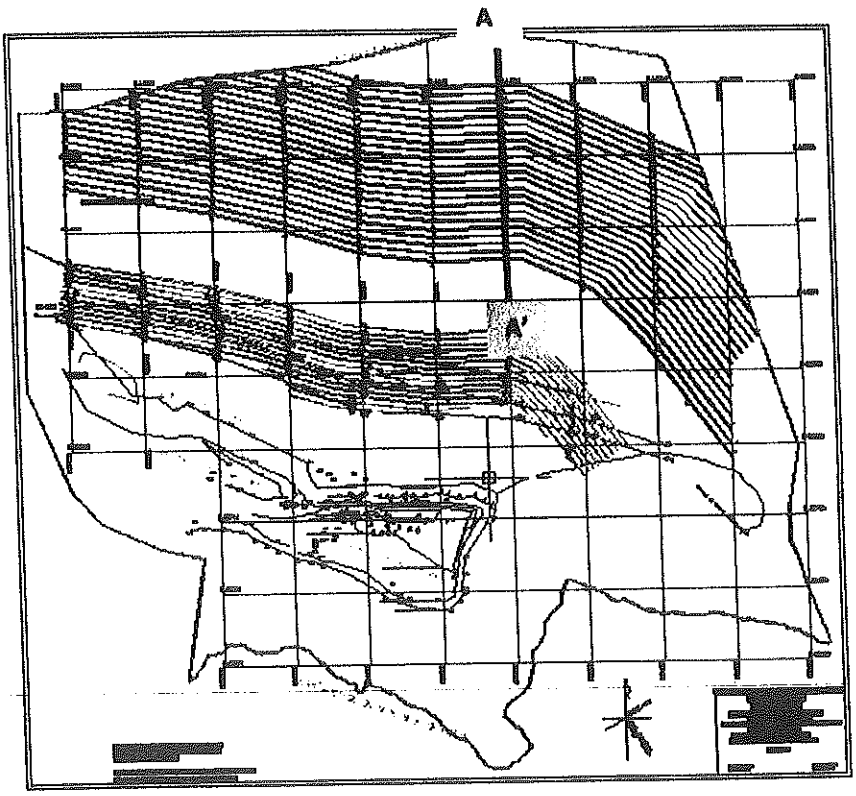


Figure 6: Surface Plan of the mine area

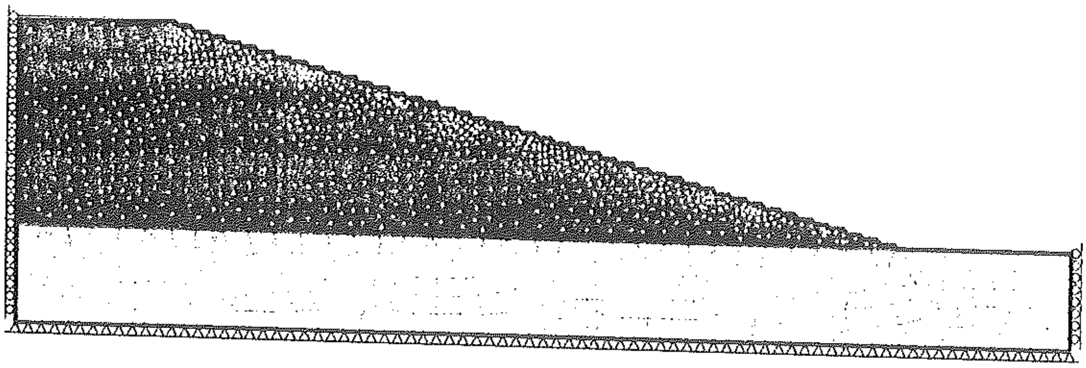


Figure 7 : Descritized view of re-handling dump slope at final stage(section AA')

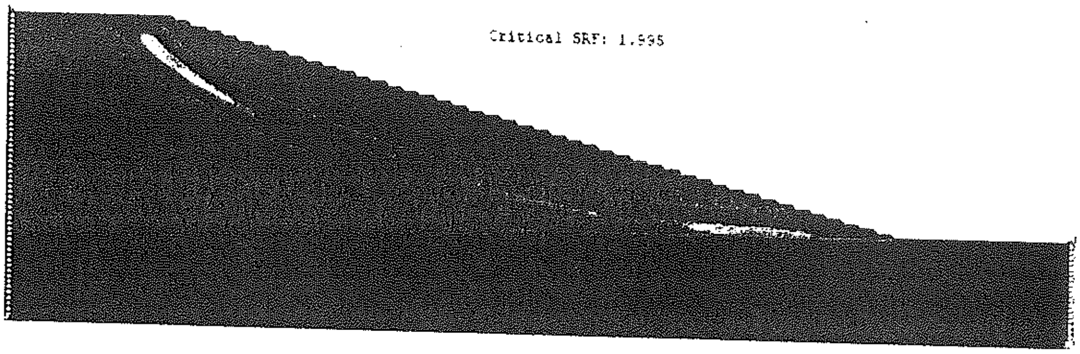


Figure 8 : Maximum Shear strain with factor of safety of re-handling dump slope at final stage (section AA')

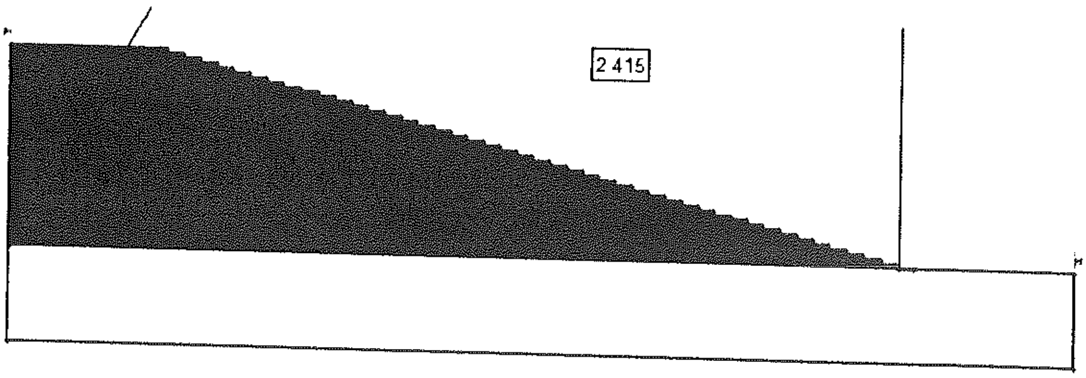


Figure 9 : Probable Failure plane with factor of safety re-handling dump slope at final stage by LEM (section AA')

Simulation of Final Benches along with insitu benches

The design of mine benches and slope profile has been collected from the mine officials. The overburden material has been dumped on solid foundation. The dump material was failed along the fault and flowed in working area. The failed material is being re-handled and dumped in other place to expose the coal below the insitu benches. A fault is also passing through the insitu benches.

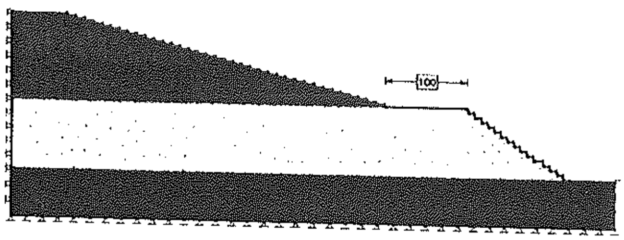
It was expected that the depth of insitu benches was at -5 MRL and location of fault is also known. However, during the removal of overburden dump material the depth of insitu benches varied from -5 MRL to -40 MRL at different locations. The location of fault place is also varying. The general guideline is 100m bench width should be left between overburden dump and insitu benches. Another factor which controls the stability of benches is fault (F-8). The fault should be exposed during the mining so that the stability of mine benches and overburden dump is stable for long term.

Therefore, another study has been carried out with varying bench width (from 25m–100m) between overburden dump and insitu benches. The individual dump bench slope is 56^0, height 3m and width 9m. The bench parameters in insitu benches are; slope angle is 70 degree, height of slope is 6m and width of bench is 6m.

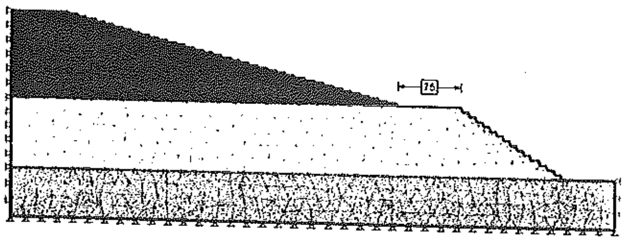
Material properties have assigned to the model as given in table 3. The complete model has got two types of material i.e. dump material on top and and insitu rock beneath it. The discretized view of dump slope is shown in figure 10. The result in terms of factor of safety and maximum shear strain has been plotted in Figure 11. The factor of safety of the slope varied from 1.51 to 1.49 from finite element method. It indicates that the slopes are stable in long term and the width of bench between overburden and insitu does not have any significant effect on overall stability. The failure circle has also been analysed (figure 11). It shows the that the slope become unstable if the distance between toe of dump slope and crest of insitu benches is less than 60m. If it is less than 60m then slip circle passes through of dump material.

Table 4 : factor of safety with distance between dump and insitu benches

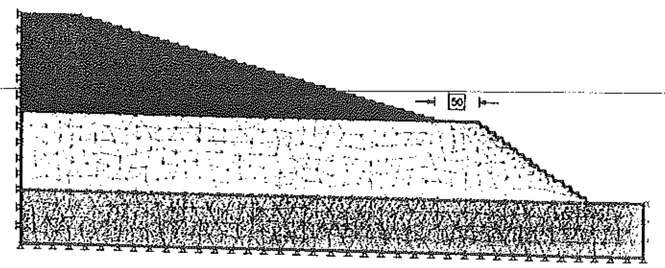
Sr No	Distance between dump and insitu benches (Corridor width) in m	Factor of safety by FEM
1	100	1.51
2	75	1.50
3	65	1.50
4	60	1.50
5	50	1.49
6	25	1.46



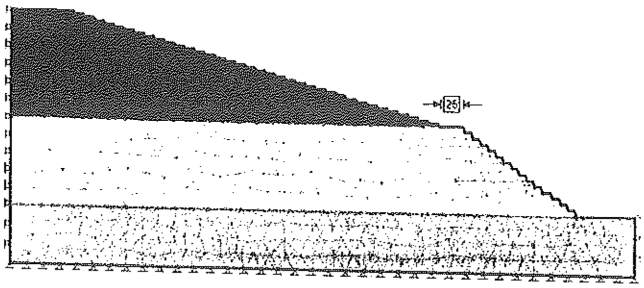
(Corridor width = 100m between overburden dump and insitu benches)



(Corridor width = 75m between overburden dump and insitu benches)

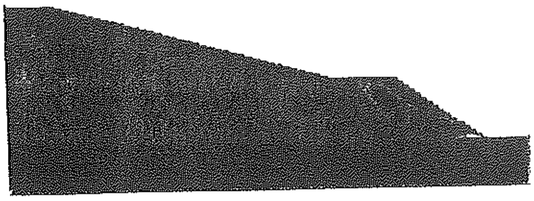


(Corridor width = 50m between overburden dump and insitu benches)

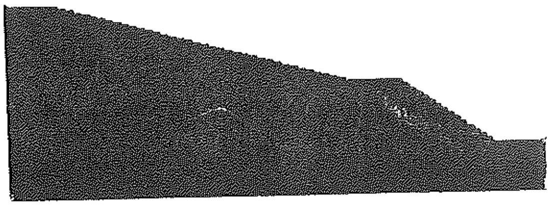


(Corridor width = 25m between overburden dump and insitu benches)

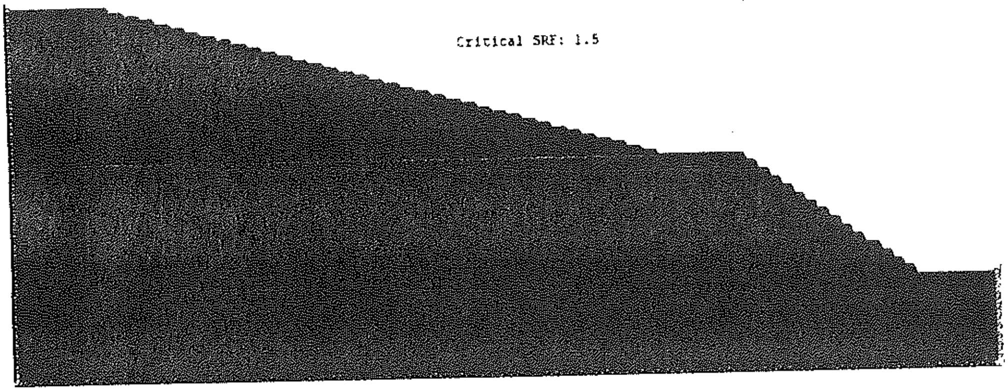
Figure 10 : Descritized view of re-handling dump slope and insitu benches



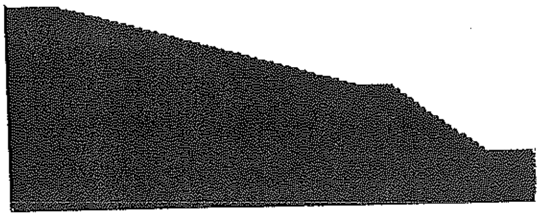
(Corridor width = 100m)



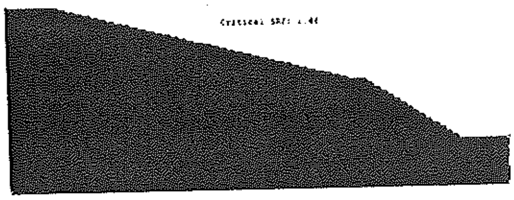
(Corridor width = 75m)



(Corridor width = 60m)



(Corridor width = 50m)



(Corridor width = 25m)

Figure 11 : Maximum Shear strain with factor of safety of re-handling dump.

Slope stability of internal dump slope

The dump overburden material has been assumed to be placed in a loose state which will allow for any free water within the dump to drain out. It has been considered that the dump foundation is horizontal and free-draining. Hence, a phreatic surface within the dump was not considered in the modelling of dump slope. The height of individual bench is 30m, width 45m and slope angle 37^0 is taken for simulation. The overall height of internal dump is 200m and overall slope angle is 20^0. The figure 12 shows the layout of internal dump slope. Figure 13 shows the Descritized view of dump slope.

The results in terms of factor of safety by numerical modelling and limit equilibrium method are shown in figure 14 and 15 respectively. The factor of safety is 1.53 and 1.528 from finite element and limit equilibrium method respectively. The slope is long term stable as the factor of safety is more than 1.50.

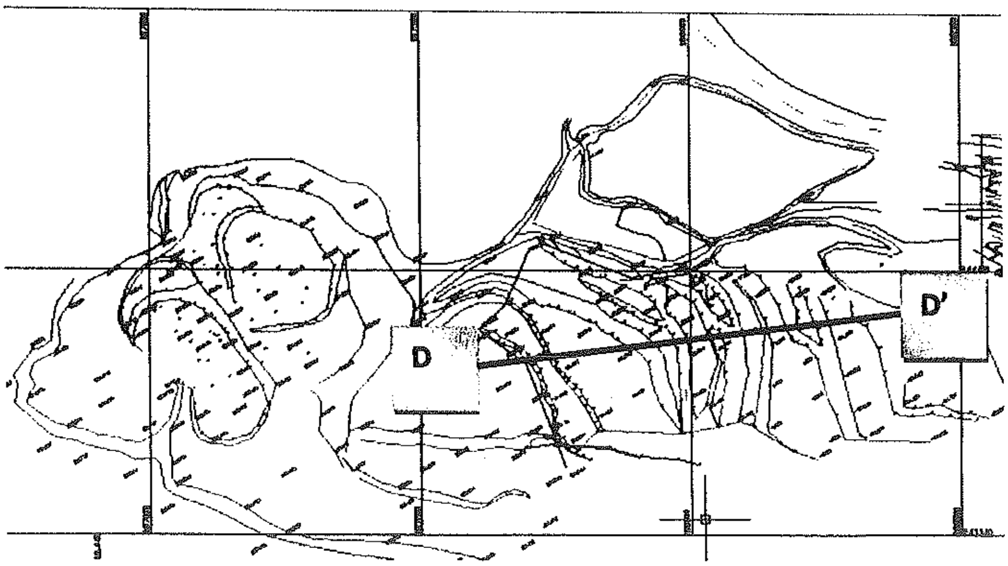


Figure 12 : Surface Plan of the mine area

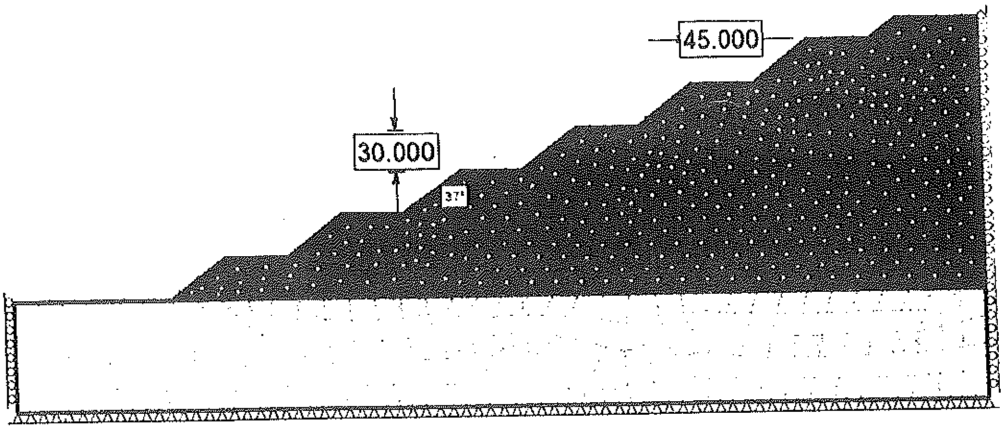


Figure 13 : Descritized view of internal dump slope for final dump (Section D-D')

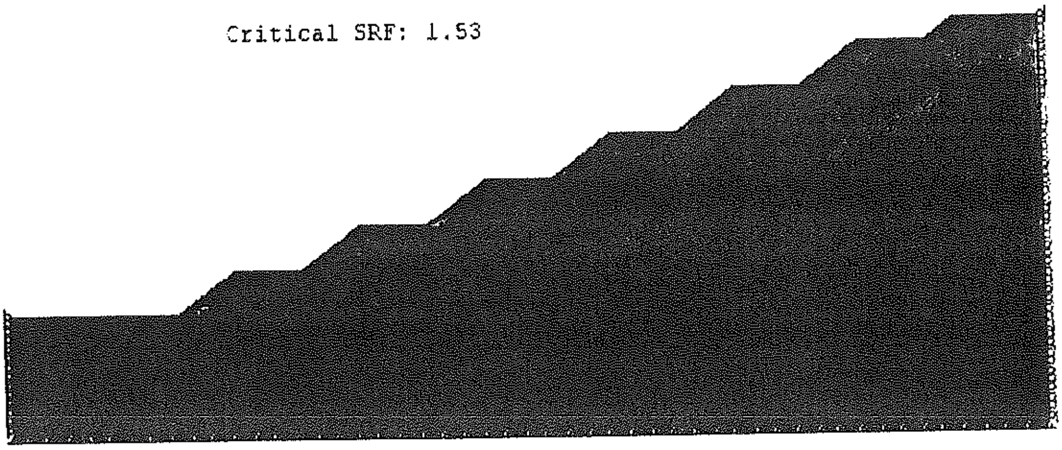


Figure 14 : Maximum shear strain with factor of safety 1.53

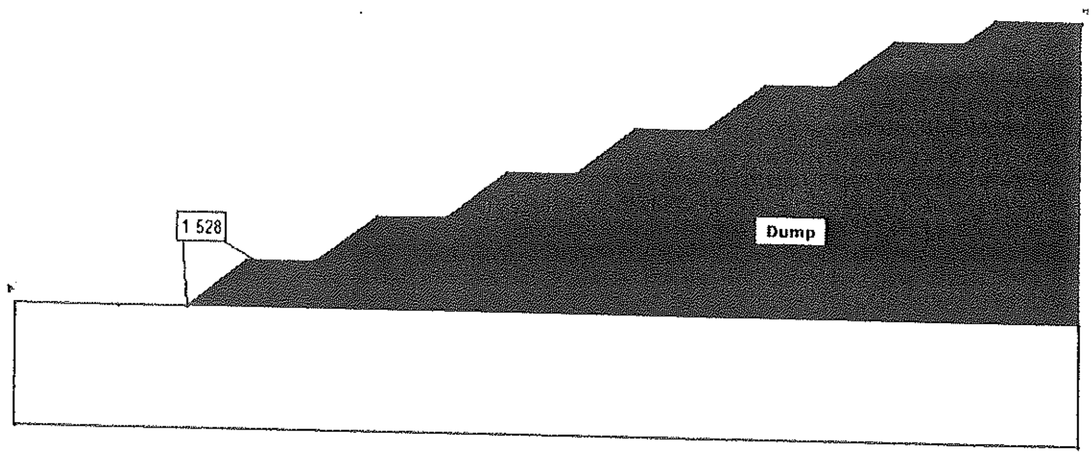


Figure 15 : Probable failure plan with factor of safety by LEM

Safe distance between internal dump and mine working

Figure 14 and 15 shows the probable failure circle of internal dump slope. It indicates that the failure initiated from bench and leads to bench failure. Therefore, the minimum safe distance considered bench failure is 30m. In the next simulation the large failure is considered. The minimum distance between internal dump and working is determined by considering the residual cohesion is strength equal to negligible and friction angle is 10 degree of dump slope. Various models have been simulated at different internal dump height (90m, 120m, 150m, 180m and 200m). The yield element have been plotted to find out the minimum distance between internal dump and mine working (figure 16-20). The recommended Minimum Safe Distance (m) is shown in table 5.

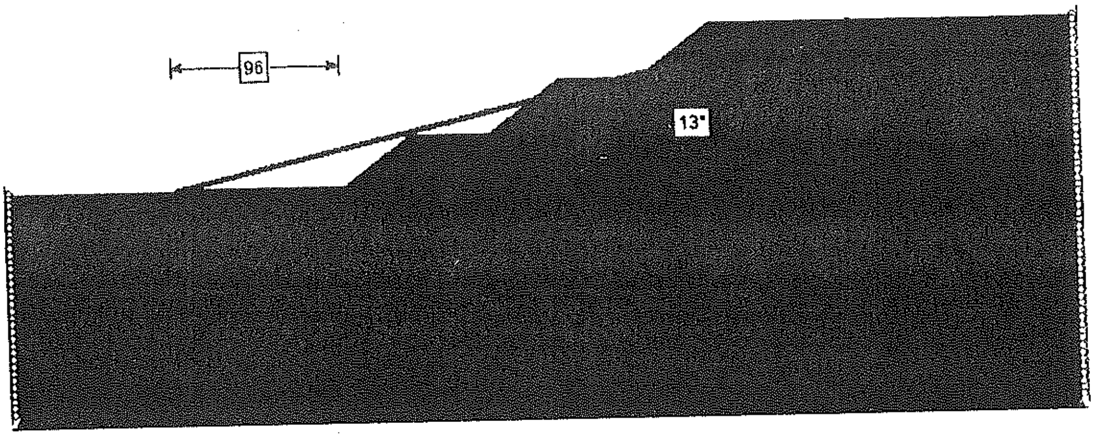


Figure 16: Yield Elements in the dump material at 90m height

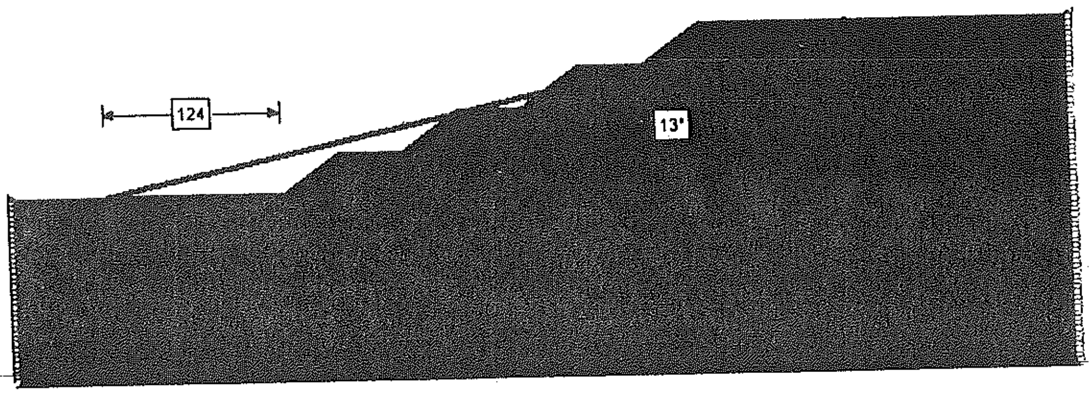


Figure 17 : Yield Elements in the dump material at 120m height

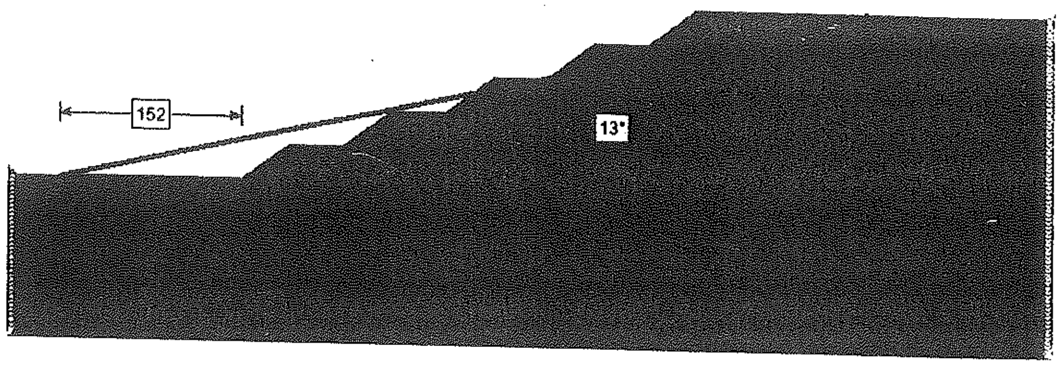


Figure 18 : Yield Elements in the dump material at 150m height

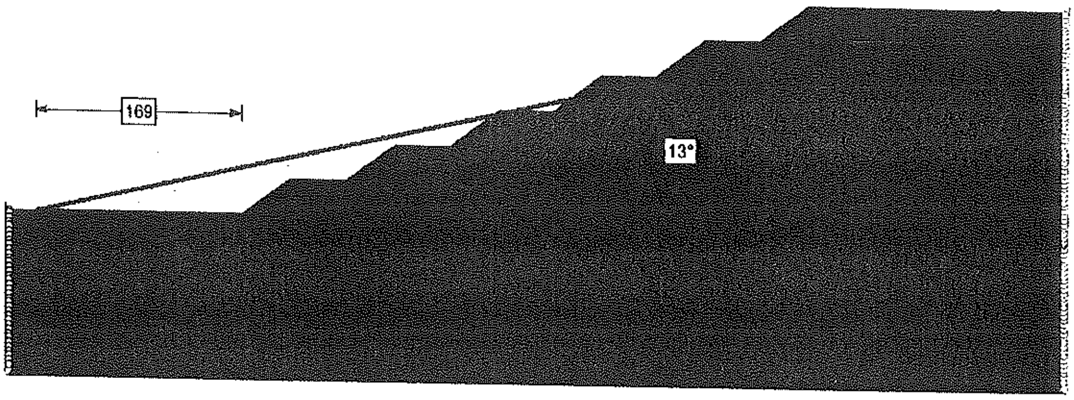


Figure 19 : Yield Elements in the dump material at 180m height

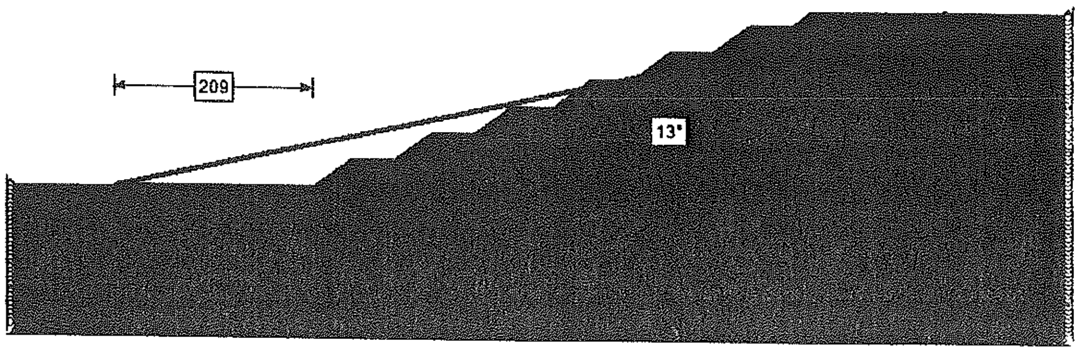


Figure 20 : Yield Elements in the dump material at 200m height

Table 5 : Minimum safe distance at different dump height

Sr. No	Dump height (m)	Minimum Safe Distance (m)
1	90	96
2	120	124
3	150	152
4	180	170
5	200	210

4.0 MONITORING OF SLOPE

A major part of the slope stability monitoring program will be the regular inspection of the bench faces and the crest areas for early evidence of slope instability. These regular inspections should be conducted ideally by the same individual in order to maintain continuity of the observations.

The purpose of monitoring for waste dump and mine slope is as follows:

- Maintain safe operating conditions.
- Provide advanced warning of developing instability
- Provide information about the instability mechanism.
- Quantify displacements and rates.
- Establish and maintain a record of facility performance.

The monitoring observations should be recorded in a diary/computer so that a record of stability performance can be maintained for each stage of pit development. The monitoring frequency will depend upon the stability of the slopes, the time of year, the rate of mining, and the nature of the mining activities that are being conducted in the open pit. The slope monitoring prisms should be surveyed monthly during the summer and winter months, provided that the results of the visual monitoring indicate that the slopes are stable. The monitoring frequency should be increased to weekly surveys during the rainy season. Intensive slope monitoring should only be required when mining operations are being conducted in the vicinity of unstable portions of the open pit slopes.

1. **Visual Monitoring:** The initial monitoring program include visual inspection of the pit slope and dump slope, specially crest, slope face and toe areas for evidence of cracking, seepage, erosion, deformation etc. It is recommended that the shift supervisor or field engineer visually inspect these areas. Other observations (cracking, seepage, erosion, deformation) should also be logged properly. Bench should have gradient in any direction for proper drainage.

2. **Conventional monitoring Technique**: Conventional prism monitoring and automated theodolites can be used to monitor the slope movement at low cost. The accuracy and precision can be improved by increasing the number of measurements. Prisms are installed on the slope at a regular spacing, 50m horizontally and 50m vertically, and on critical areas throughout the open cast in staggered pattern. Locations of those prisms should be measured every week but it should be increased (i.e on daily basis) during rainy season or when any displacement is observed. The Survey Department is responsible for maintaining the theodolites and prisms and for collecting and storing the data. The rock engineers then analyse the data, looking for significant movement, and report any potential areas of slope failure to the mining personnel.

   The graphs of displacement, velocity and vector movement should be plotted on regular basis for each ends every prism. Movements should be checked in all three directions (X, Y and Z direction). Displacement velocity should also be plotted for prisms located in critical areas. The alarms sound when 30mm displacement or 50mm/2 hours velocity is recorded (Little 2006). If an alarm is sounded, the Survey department should check weather this due to survey error. If not than Rock engineering department should investigate the area of concern. If slope movement occurs in a working area then it should be evacuated until it is declared safe. Permanent station along with prism can be installed a regular interval for better accuracy and automatically monitoring by Robotic total station.

   1. **Robotic Total Station with automatic monitoring**

      - Trimble S7 1'': Auto Rotating, Target Tracking, Searching, Prism monitoring with report of user define time interval. Create 3D Models.

      - Leica Nova MS60: Digital Imaging and 3D scanning, 1'' accuracy, automatic focus.

3. **Advanced monitoring technique:** Slope monitoring Radars can be used for continuous 24x7 monitoring as well as live monitoring data analysis. For critical slope monitoring, Radar is the best technology to predict slope behavior and deformation trend. Sometimes, Time of Failure can be predicted using inverse velocity method analysis of Radar data. The system scans a region of the wall and compares the phase measurement in each region with the previous scan to determine the amount of movement of the slope. An advantage of radar over other slope monitoring techniques is that it provides full area coverage of a dump slope without the need for reflectors mounted on the rock face. The system offers sub-millimetre precision of wall movements without being adversely affected by rain, fog, dust, smoke, and haze. The real-time display of the movement of mine walls has allowed continuous management of the risk of slope instability at mine level operations.

   Advantages of using radar are-

- Broad area coverage (upto 5km)
- Fast scanning using electro-magnetic waves perform
- High accuracy (upto 0.2mm)
- Live data and alarming system

   But all those can be achieved by-

- Selection of stable ground base for radar Installation
- Proper installation of data transformation system (i.e. modems, antennas, repeaters and servers) to minimize the delay in data transfer.
- Deciding the proper deformation limit for alarming system. Alarming system should be in audio visual in the PMP and SMS/ mail in mobile phone.
- Appointment of competent geotechnical engineer to analyze and interpret Radar data as well as to understand the slope behavior considering real/ erratic deformation.

Reutech Radar System

MSR 250: Movement and surveying Radar

- 3-Dimensional data point spacing
- At 1000 meters: 0.5m x 4.4m x 0.44m
- Measurement Accuracy: Sub-millimeter

Ground Probe (SSR)

SSR-XT

- 3D Real Aperture Radar
- sub-millimetre deformation measurement accuracy
- SSR-XT is extremely durable
- highly mobile, Fast and flexible
- automatically generates a powerful, high-density 3D model of the mine

IDS GeoRadar

IBIS ArcSAR Performance:

- Scan range: up to 5000m
- Maximum coverage: 360° H x 120°V
- Resolution: 10 million pixels for full resolution scan
- 3D SAR1 and automatic DTM survey

Reigl VZ 4000

- Very long range up to 4000 m
- Wide field of view, 60° x 360°
- High speed data acquisition up to 222,000 meas./sec
- High accuracy, high precision
- Optional waveform data output

The monitoring process is site specific dynamic. It starts with daily visual inspections of slopes, check of a ground water level as well as data from the monitoring system. Prakash el.al. (2015) proposed time frame at which certain movement has to be monitoring (table 5).

Table 6: Suggested monitoring frames

Sr. No	Point undergoing movement	Frequency of monitoring
1	0mm to 2mm per day	Once per month
2	2mm to 5mm per day	Once per week
3	5mm to 10mm per day	One every 2 days
4	10mm to 50mm per day	Once per day
5	>50mm per day	Require continuous observation l

Table 7: summary of the movement thresholds suggest by various authors

Author	Movement thresholds	Actions Description
Martin (1993)	0.1mm/day (0.004 mm/hr)	Initial rock mass response
	0.2 to 2 mm/day (0.008 to 0.08 mm/hr)	Strain hardening
	10 - 100 mm/day (or more) (0.4 - 4.1mm/hr)	Progressive failure
Flores and Karzulovic (2001)	Less than 10mm/day (0.4mm/hr)	Conditions normal; no indication of instability
	10 - 30mm/day (0.4 to 1.25mm/hr)	More detailed monitoring required Appearance of cracks
	30 - 50mm/day (1.25 - 2.1mm/hr)	Potential for instability (if ongoing for longer than 2 weeks)
	More than 50mm/day (2.1mm/hr)	No mining allowed
Zavodni (2001)	0.1mm/day (0.004 mm/hr)	Initial response
	Less than 17mm/day (0.71 mm/hr)	No failure expected within 24hrs
	Less than 15mm/day (0.63 mm/hr)	No failure expected within 48hrs
	More than 50mm/day (2.1 mm/hr)	Indicates progressive failure (total collapse expected within 48 days)
	More than 100mm/day (4.2 mm/hr)	Clear mining area (Progressive geometry and progressive velocity)
	150mm/day (6.25 mm/hr)	Clear mining area (Regressive geometry)
Naismith and Wessels (2005)	84 mm/day (3.5mm/hr)	Alert : Increase monitoring assessments
	120 mm/day (5 mm/hr)	Alarm : Inform operations
	240 mm/day (10 mm/hr)	Scram : Pit evacuation
Roux, Terbrugge and Badenhorst (2006)	0.1 mm/day (0.004 mm/hr) for 3 days ; downward vertical movement	Red alert
	0.2mm/day (0.008 mm/hr)	Evacuate
	0.5 mm/day (0.02 mm/hr) for 10 days; horizontal movement	Orange alert
	1.0 mm/day (0.04mm/hr) for 3 days; horizontal movement	Red alert
	2.0 mm/day (0.08mm/hr) horizontal movement	Evacuate
Sullivan (2007)	0.1 - 0.25 mm/day (0.004 - 0.01 mm/hr)	Definite movement of slope related to shear of displacement on structures
	0.25 - 0.5 mm/day (0.01 - 0.02 mm/hr)	Likely to fail sometime in future
	1 mm/day (0.04 mm/hr)	High chance of failure
	More than 1.0 mm/day (>0.04 mm/hr)	Pre-failure collapse movements

5.0 CONCLUSIONS AND RECOMMENDATIONS

The stability of dump slopes was carried out for Rajmahal Opencast mine. Finite element method and Limit equilibrium method has been used for analyzing the dump slope for different geo mining conditions. The factor of safety of 1.2 to 1.5 has been taken as short stability & Factor of safety > 1.5 for long term stability.

Two cases of dump slope stability have been carried out in the present work. First is slope stability of slope in re handling dump area and other is slope stability of internal dump slope. There was failure in the overburden dump slope. It has been recommended by scientific investigation that the height of dump must be reduced for the stability point of view. Therefore, overburden is being re-handled to comply with recommendation of scientific investigation. This is terms as re-handling dump area. The conclusions and suggestion of the present study are summarized below.

- The minimum factor of safety for existing mining dump condition is 1.72. It indicates that the present condition of dump slope is stable.
- The factor of safety of final dump slope of rehandling area is 1.98 and 2.41 by FEM and LEM. It indicates that the dump is stable for long term at present configuration.
- The factor of safety dump slope is 1.53 and 1.528 by FEM and LEM. It indicates that the dump is stable for long term at present configuration.

- The recommendation for bench height and width for re-handled dump is given below in table:

[redacted]					
1	Re-handed dump	3	56	9	15

- The recommendation for bench height and width for over burden dump is given below in table:

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	Overburden Dump	30	37	45	20

- The minimum bench should be left between overburden dump benches and insitu benches.
- The dumps should be developed by keeping a safe distance from the toe (at the lowest level) of the dump to any permanent structure/installation/working to avoid any damage near the toe of the dump. The minimum distance is depended on height of dump slope. The recommended minimum distance is given below in table:

Sr. No	Dump height (m)	Minimum Safe Distance (m)
1	90	96
2	120	124
3	150	152
4	180	170
5	200	210

- Adequate infrastructure to be provided for imparting training on slope stability to all concerned person employed in such large open cast mines. Technical competence of the contractual supervisors shall be appropriately scrutinized before deploying them in the mine.

- The fault will be exposed and rock mass near the fault can be observed during the excavation in insitu. It is likely that the rock mass near the fault is disturbed. Therefore, it is recommended that the rock mass near the fault must be observed during the excavation. If the rock mass is disturbed near the fault then the design of bench in terms of height and width shall be freshly carried out based on scientific study. It is also recommended that the fault plane should be excavated and removed through benching.
- Each stage of dump should be compacted by compactor/HEMM for better inherent strength of the dump material.
- Proper levelling at the top of the dumped material should be done to minimise the infiltration of water inside the dumps. Care must be taken in the construction of dumps to ensure that there is no impoundment of water on the top of the dump because it is highly detrimental to dump stability. A proper gradient helps for quick run-off of water. Care must be taken to avoid saturation of dumps by ensuring that the infiltration is minimised. The flooding of the dump edges/dump toe should be avoided. The dump base should not be in continuous contact of water.
- Proper leveling of the dumped material should be done with the help of dozer. It will help to consolidate the dumped material and will minimize the infiltration of water inside the dumps. The upper slope surface, immediately behind the crest, is an area of considerable potential danger. The water, which is allowed to pond in this area, will almost certainly find its way into the slope through cracks and fissures. Grading of this surface will enhance run-off of any collected water.
- The vegetation is certainly the best method of slope surface protection, as they will bind the surface together. In turn, it will reduce surface erosion considerably and will tend to inhibit the entry of water into the slope. The biological reclamation of the dumps should also be done by planting the local self-sustaining plants on the final dumps. It increases the stability of dumps. Steps should be taken to ensure that the stability of the dump should be progressively increased by remedial measures, like vegetation growth, drainage and benching.

- The dump foundation should be kept in drained condition. The gradient along the floor of the dump should be properly maintained for free flow of water. There should not be any dumping in a pool of water or on slushy ground.
- Dump floor also influences the stability of dumps. If the foundation of dump is smooth/slippery, the foundation of the dumps should be roughened for better binding between the floor in-situ material and dumped material.
- The first sign of instability is a tension crack. So, it is important to carry out regular inspection to detect the development of tension cracks on the crest of the slope as well as on benches and to carry prompt remedial measure. They may develop as a function of toe cutting and high water pressure in the dump. The opening of cracks will tell whether, pick up any seepage, their position should be marked with stakes and that point should be inspected during all inspections. If the inspections detect cracks or other sign of instability then the stability of the dump should be reviewed and remedial measures should be applied.
- Slopes do not fail without warning and may be managed through design of sequencing, resloping of selected areas to shallower angles, and carrying out monitoring. Slope monitoring should be established as part of the monitoring and geotechnical program for the site. A special monitoring organization cell should be created under the responsible officer for supervising and implementation of all the protection measure and abnormal seepage of water in quarry indicates the danger of slope failure.
- The monitoring program should include visual inspection of the pit slope and dump slope, (specially crest, slope face and toe areas) for evidence of cracking, seepage, erosion, deformation etc. It is recommended that the shift supervisor or field engineer to visually inspect these areas. These observations (cracking, seepage, erosion, deformation) should also be logged properly. Continuous slope monitoring is essential to detect any instability in advance to safeguard against possible slope failure. The dump shall be regularly surveyed to produce up to date & accurate dump geometry.

- The monitoring should be done using Total station and Laser scanner (Reigl VZ 4000). The theroshold value for slope monitoring and interpretation has given in table 6.
- The Monitoring by Total station should be done on weekly basis and physical inspection on daily basis. The monitoring stations should be installed at an interval of 100 meter in staggered manners so that effective gap between two stations of two immediate upper and lower benches would be 50 meters only. If any movement is observed then the frequency of monitoring should be increased and it shall be immediately informed to higher management. If the symptoms are abnormal, it must be referred to DGMS authority and the work should be stopped till further instruction from statutory bodies are obtained.

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FINAL REPORT

On

DUMP SLOPE STABILITY STUDY FOR RAJMAHAL OCP

GODDA, JHARKHAND

69
11/02/2020

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June, 2018

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1.0 PROJECT PROFILE

1.1 Introduction

Project Report for Rajmahal opencast was originally sanctioned in August, 1980 for a rated capacity of 5.0 MTY. The project was subsequently expanded to a rated capacity of 10.5 MTY, the PR for which was sanctioned in November, 1988. This PR based on the project documents of Rajmahal-A OC Mine (10.5 MTY), prepared by METCHEM, Canada Inc. in Sept. 1987. Subsequently, a Revised Cost Estimate of Rajmahal OCP (10.5 MTY) was sanctioned by the government in July, 1993.

The Projection Report for Rajmahal Expansion OCP (10.5 Mty to 17 Mty) has been prepared based on the projection parameter of the Expansion projection for 17 Mty.

1.2 Scope of the work

Scientific study of Dahenangi Patch for

a). Slope Stability analysis of Dahenangi Patch

b). Design of bench height, width and ultimate pit slope

1.3 Geology and hydrogeology

Rajmahal OCP lies within Lalmatia Exploration Block which covers an area of 15 Sq.Km. and has been explored by CMPDI. The geological report of the block was published in March 1984 considering the data from 200 boreholes. This geological repot forms the basis of the approved PR of 10.5 MTY capacity.

Altogether eight persistent coal horizons of Barakar formation have been identified in the block. The seams, from bottom upwards are seams I, II (Bot), II (Top), III, IV, IX, X & XI. The seams II (Bot), II (Top), III merge and split of seams within the area to from various combinations. These seams are also highly inter-banded in nature. More than 95% of the reserves in the block occur in the seams II (bot), II (top) and III along with their various combinations. Seams-I is not developed properly in the geological block except in the central part. The approved project report does not include seam-I in the quarry proposal. Therefore, the floor of the seam-II (bot) form the base of the OCP as per the approved PR.

All the seams are incropping in the area under a thick alluvium cover of 15m to 35m in thickness and dips gently (usually 2^0 to 3^0) toward east. However, higher dips upto 10^0 is also noticed in the vicinity of structure disturbances particularly in the area lying south of fault F_8.

1.3.1 Regional Geology

The Rajmahal coalfields consists of a series of lower Gondwana exposures aligned roughly in the N-S direction along the foot of the Rajmahal hills. The Rajmahal traps capped Rajmahal hills have receded considerably toward east in the areas toward north near Ganges exposing large areas of the coal bearing Barakars beneath. The Barakars have been identified to lying with a depositional contact on the Archeans which lie towards west. In addition to these lithostratigraphic units, Talchir (underlying the Barakars) and Dubrajpurs (underlying the Rajmahal traps) have also been found exposed in parts of these coalfields.

1.3.2 Geology of the Block

The Lalmatia block from the northern most part of Hura coal prospect. The general stratigraphic sequence within the block is as follows.

Table 1 : Stratigraphic sequence of Lalmatia Block

Group	Formation	Lithology	Thickness Range(m)
Recent to Sub-recent	Alluvium	UNCONFORMITY	0-15
Upper Gondwana	Rajmahal Traps	Rajmahal volcanic and inter-trappean sandstone and shales. UNCONFORMITY	50
Lower Gondwana	Barakar	Coarse to medium grained sandstone with shale and coal	25-350
		Coarse arkosic sandstone, pebbly at places	15-`50
	Talchirs	Sandstones and shalesTillites	10-20
		UNCONFORMITY	
		Granite gneisses, hornblende Schists and pegmaties	

1.3.3 Coal Seams :

Twelve co-relatable coal seams have been deciphered from the borehole data within the block. These have been named as seam-I to seam-XII in ascending order. Out of these, five seams namely seam-V to seam-VIII and seam-XIII show. Seams IV to XII have been found only in areas south of Fault F8 which down throws southwards by 60m whereby preserving additional thickness of sedimentary.

17 normal faults have been postulated within the block. Among these, five southward heading faults, namely Faults F1, 5, 8, 11, and 15 are of major magnitude. As borne out of the interpretation, the southern half of the block appears to be structurally more complex.

1.3.4 Hydrogeology

Five aquifer horizons have been identified in the block as per the hydro-geological investigation conducted in the Lalmatia block by CMPDI. The projected make of ground water discharge during the 6th year was original estimated by CMPDI as 8.4 MGD. However this was later revised to 3.92 MGD (during 6th year) I July, 1991 based on further studies conducted by CMPDI. The detailed hydrogeological investigations have been conducted by CMPDI in the Rajmahal project area and a report on Hydro geological investigations has been published in November 1994. Later (in july, 1991) a report on the Advance Mine Dewatering Arrangements at Rajmahal Project was published by CMPDI based on further studies.During the studies, five major aquifer systems were identified as follows.

Table 2 : Major aquifer system in Rajmahal project

Aquifer Disposition				
Sl. No	Aquifer	Lithology	Confining beds	Nature of Aquifer
1	Water table Aquifer	Clay slit and sand		Unconfined
2	Aquifer-III	Sandstone	Top clay and seam-III	Confined to Semi-confined
3	Aquifer-IIA	Sandstone	Seam-III and Seam-II(top)	confined
4	Aquifer-II	Sandstone	Seam-II(top) and seam-II(bot)	confined
5	Aquifer-IA	Sandstone	Seam-II (bot) and seam-I	confined
6	Aquifer-I	Sandstone		confined

From the sump tests it has been calculated that the permeability of over burden is in between 2m/day to 3m/day and the specific yield is 15% whereas, for the lower aquifers, the permeability ranges from 5m/day to 8m/day and the storability is 14X10.5.

1.3.5 Climate

The area is characterized with mild to moderate, tropical to sub-tropical climate, with cold winters and fairly hot and dry summers

During pre-monsoon, light rain is noticed and during monsoon 80% of annual rail fall occurs and weather is cooler due to rains.

The meanof maximum temperature is 30.70^{0}C and mean ofminimum temperature is 18.92^{0} C and the average of the maximum and minimum is 22.8^{0}C.

1.4 Location

Rajmahal opencast mine, under the administrative control of ECL is located in the Godda district of Jharkhand. It lies between latitude 24^0 1" 12' N and $25^0$03" 15' N and longitudes 87^0 25" 0' E and 87^0 24" 52' E. the site of Rajmahal Opencast mine is accessible by road from Suri (120 km. to the south) or from Sahibganj (50 km. to the North-East). Its nearest railway station is at pirpainti approximately 32 km. North of the area.

1.5 Mining System

The proposed mining system envisaged deployment of shovel-dumper combination for both coal production and OB removal. The thick(15m-35m) mantle of alluvium cover and weathered mantle and above the coal seams which has been called as consolidated OB in the Project Report have been proposed to be worked by 20 m^3 long reach Rope Shovels in conjunction with 170T Dumpers A thickness of up to 20m of the unconsolidated OB was envisaged to be excavated by $20m^3$ long reach Rope Shovels standing on the hard floor at the top of consolidated OB by deploying. hydraulic Excavator with a $4.4/5m^3$ backhoe bucket of 12m digging depth (basic machine same as $12m^3$Hydraulic Shovel).

The balance waste material in the form of parting and bands was proposed to be removed by $12m^3$ Hydraulic shovel in conjunction with 85T Dumpers.

For coal production, $10m^3$ Rope shovels and $12m^3$ Hydraulic shovels were proposed with 85T coal body dumpers.

1.6 Mine Boundary

As per the approved PR the mine area has been delineated within a maximum OB: Coal thickness ratio of 3.4 :1 at the floor of seam-II (bot) so as to restrict the operations within a maximum stripprng ratio of $2m^3$. Per te. This has resulted in the exclusion of the following seams/areas.

(a) Seam-I in the central part of the deposit where it is developed with a thickness of 2m to 6m below a parting of 13m to 34m with the overlying seam-II.

(b) Northern and eastern part of the block and

(c) Most of the coal under Lalmatia hill (68m-104m high)

The mining block as delineated in the approved P.R was grouped into three areas, namely (i) initial mine area which includes the incrop Zone (ii) the main mine area and (iii) the deep mine area generally bounded by fault F_2 and F_{15}. The deep mine area was also excluded from the 25 year mine plan due to the deep seated highly faulted coal seams rendering them difficult to mine.

1.7 Reserves & Stripping Ratio

The geological reserves of the approved P.R as estimated by M.Ss. METCHEM was 493.04 Mt including a reserve of 97.22 Mt in the deep mine area. Out of the above mineable reserves, 240.10 Mt was proposed to be exploited up to 25th year of the OCP with an average stripping ratio of 1.57 m^3/t (for the first 25 years).

1.8 Quarry Boundaries

The quarry boundaries of the present Project Report (17.00 Mty) has been kept almost the same as the boundary envisaged in the approved P.R. (10.5 MTY) except in the following areas.

i) a portion of the incrop zone lying to the west of Lalmatia hill which was a part of the mine take area in the approved P.R (10.5 MTY) could not be worked due to problems encountered by heavy earth moving machinery in working over the developed workings. About 0.6 Mt of coal could not be mined. The area has now been blanketed by OB dumping.

ii) As per approved P.R, a small part of the Lalmatia bazaar village was falling within the OCP excavation area the boundary of the OCP has been modified in the present report so as to skirt this village/bazaar area by a distance of about 100m.

iii) The limit of the OCP has been marginally withdrawn towards the north in the foothills of Gandheswari hill occurring in the south of the OCP to avoid excavation in Gandheswari hill/forest area.

iv) Dip side boundary has been extended upto 1.5 cut of ratio line.

v) About 14 Mt of reserves of the deep pit area have been added to the reserve at an average stripping ratio of 1.6 cum/t.

1.8 Dump creation and dump failures at Rajmahal OCP

- An old dump was present on the north side of present working outsourced patch allocated to M/s MIPL-NAKS (JV). The height of the dump was approximately 40m -98 m from solid bench.
- The dump is spread over old excavated area on up throw side of fault.
- Further dumping over the above said existing dump was carried since 2007 onwards.

An accident had occurred in the Rajmahal OCP at 7.30 PM on 29.12.2016 in the deep mining area while operations were going on to remove loose overburden (re-handling) in the southern side of the mine. The operations were being carried out through outsourcing agency namely M/s. MIPL/NKAS. While removal of loose OB was going on, a large area measuring about 600m x 110m slide down by 30 m. It leads to trapping of men and machinery working on the site in the overburden material.

2.0 METHODOLOGY OF THE STUDY

The stability analysis was done by finite element method. This method has been used to assess the failure mechanisms and to determine the factor of safety. This technique is widely used to perform stability analysis where the condition are complex and possible consequences of failure are significant. Modeling has advantages that design ideas can be tested, different material properties can be evaluated and risk analysis carried out.

2.1 Geotechnical Assessment of Dump Material

The mine is being worked by shovel-dumper combination. The stability of the slope primarily depends on the strength properties of the dump material, orientation and geology of the dump foundation, infiltration of the rainfall, drainage and groundwater condition within the slope.

The Factor of safety of 1.5 has been considered for long term stability of the dump slope. However, due to previous accident in Rajmahal OCP and various uncertainties and discussion with competent authority and mine official, the Factor of safety more than 2.5 has been considered as long term stability for the present study. The angle of repose was considered to be 37°. The stability analysis has been carried out to determine the safe dump slope configuration. The foundation of the external dump should be hard strata. Each stage of dump should be consolidated by compactor for better inherent strength of the dump material.

Engineering properties of the dump material are important in analysis for slope stability. Samples were collected from mine area and tested in the laboratory. Table 3 shows the material properties used for simulation of dump slope of Rajmahal Overburden. The data is obtained by testing in the laboratory investigation and literature survey.

Table 3: Geotechnical properties of dump material.

Properties / Type of Material	Cohesion (kPa)	Friction angle (degree)	Modulus of Elasticity (MPa)	Poisson Ratio	Density gm/cc
Overburden	46	31	800	0.32	1.8
Insitu rock	1000	36	2000	0.28	2.4

2.2 Numerical Modeling (Finite Element Method)

The Numerical modeling is widely used to compute stresses and displacements in structures caused by applied load. The method is particularly useful for complex problems. The stability of a slope cannot be determined directly from finite element analyses, but the computed stresses in a slope can be used to compute a factor of safety. Phases2 based on finite element method has been used to calculate the factor of safety by shear strength reduction technique.

The shear strength reduction technique has two advantages over the conventional approach. The critical failure surface is found automatically and it is not necessary to specify the shape of the failure surface. To perform slope stability analysis with the shear strength reduction technique, simulations are run for a series of increasing trial factor of safety, F^{trial}. (Griffiths and Lane, 1999) The actual shear strength properties cohesion (c) and internal friction angle (Φ) are reduced for each trial according to the equations 1 and 2. If the multiple materials are present, the reduction is made simultaneously for all materials. The trial factor of safety is gradually increased until the slope fails. At failure, the safety factor equals the trial safety factor. The factor of safety is defined according to the equation

$$C^{trial} = \frac{1}{F^{trial}} C \quad \text{......(1)}$$

$$\phi^{trial} = \arctan\left(\frac{1}{F^{trial}}\tan\phi\right) \quad \text{......(2)}$$

The numerical model of slope has been developed based on finite element method and finite difference method. The key success of numerical modeling is to consider the representative constitutive behaviour of dump material. It has been observed from the literature that dump (soil) behaves as a non-associated elasto-perfectly plastic material. Generally, it obeys Mohr-Coulomb yield function. It can be expressed as:

$$\sigma_1 = 2C\left(\frac{\cos(\phi)}{1-\sin(\phi)}\right) + \sigma_3\left(\frac{1+\sin(\phi)}{1-\sin(\phi)}\right)$$

Where, C and Φ are cohesion and internal frictional angle

σ_1 and σ_3 are principal stress

The factor of safety generally used is in the range of 1.2–1.5 for open pit mines. This factor of safety could either be directly calculated based on limit equilibrium method or indirectly by numerical modeling based on strength reduction technique. The factor of safety must be greater than 1 for stable slope. Due to uncertainties involved in determining the properties of material, leaving some of the parameters in simulation for simplification and presence of some external factors that are not considered for simulation, it is advisable to have minimum factor of safety of slope as 1.5. The ranges of minimum total factors of safety as proposed by Terzaghi and Peck and the Canadian Geotechnical Society are given in Table 4 (Duncan and Christopher 2004). Keeping the above discussion in mind, Factor of Safety of 1.2 to 1.5 is considered as short term stability and Factor of Safety of 1.5 and above may be considered for long term stability. However, due to previous accident in Rajmahal OCP and various uncertainties and discussion with competent authority and mine official, the Factor of safety more than 2.5 has been considered as long term stability for the present study.

Table 4: Values of minimum safety factors (Duncan and Christopher 2004)

Failure type	**Category**	**factor of Safety**
Shearing	Earthworks	1.3–1.5
	Earth retaining structures, excavations	1.5–2.0
	Foundations	2–3

3.0 STABILITY ANALYSIS

Figure 1 shows the surface plan of Rajmahal Opencast Coal Mines. The Sections along the mine dump have been taken in consultation with officials for simulation of slope and dump stability. Finite Element method is used to assess the stability of slope. A major failure of slope has taken place in the year 2016. Three scenario/cases have been analysed. First set of analysis has been carried out for pre failure case. This has been carried out so that models are validated and to ensure that assumptions are correct. Second set of analysis is for present condition (patch work). In the final set of analysis, final design of bench width and height (as proposed by mine officials) has been simulated.

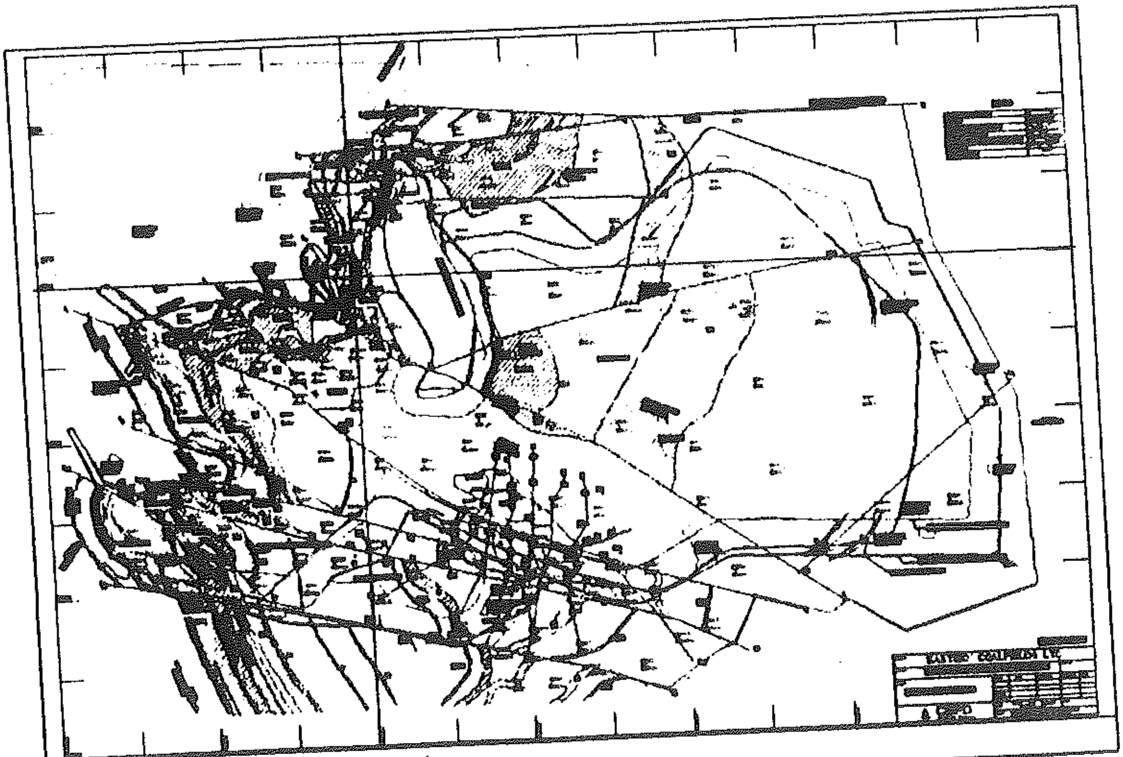


Figure 1: Surface Plan of the mine area.

3.1 Simulation of Failed Dump

Dump slope has failed in Dec 2016. The dump slope before failure has been termed as profile before failure. After failure it has taken another profile shape. Based on recommendation of HPC (High Powered Committee) the profile of dump is being altered. The present scenario is termed as patch work profile. Dump before failure and patch work as been simulated and factor of safety is calculated by strength reduction technique. The figure 2 shows the surface mine plan. The various sections have been drawn and descritised by finite element method (figure 3-4). The results in terms of factor of safety and shear strain are shown in figure 5. The factor of safety is varied from 1.1 to 1.35 (table 5). It shows that at some section the slope is not stable and it may fail if the conditions are adverse.

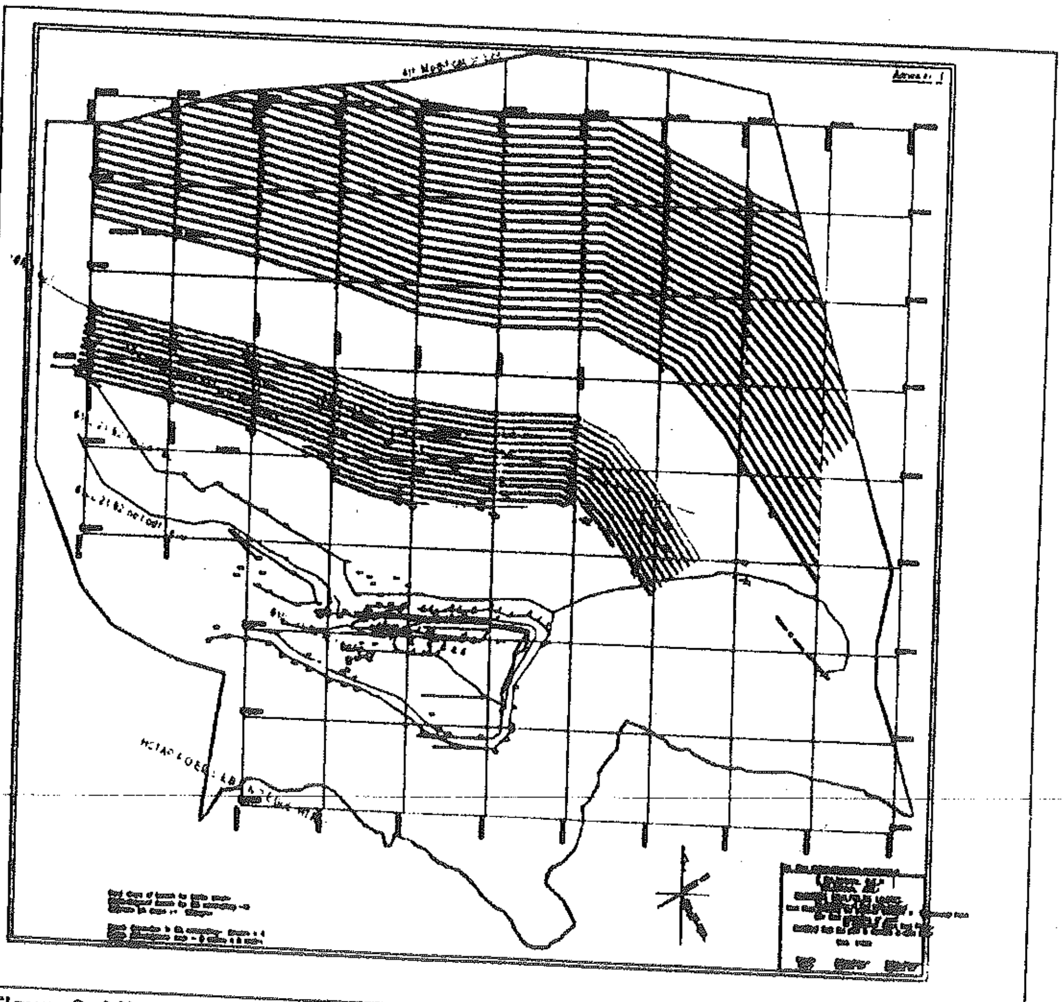
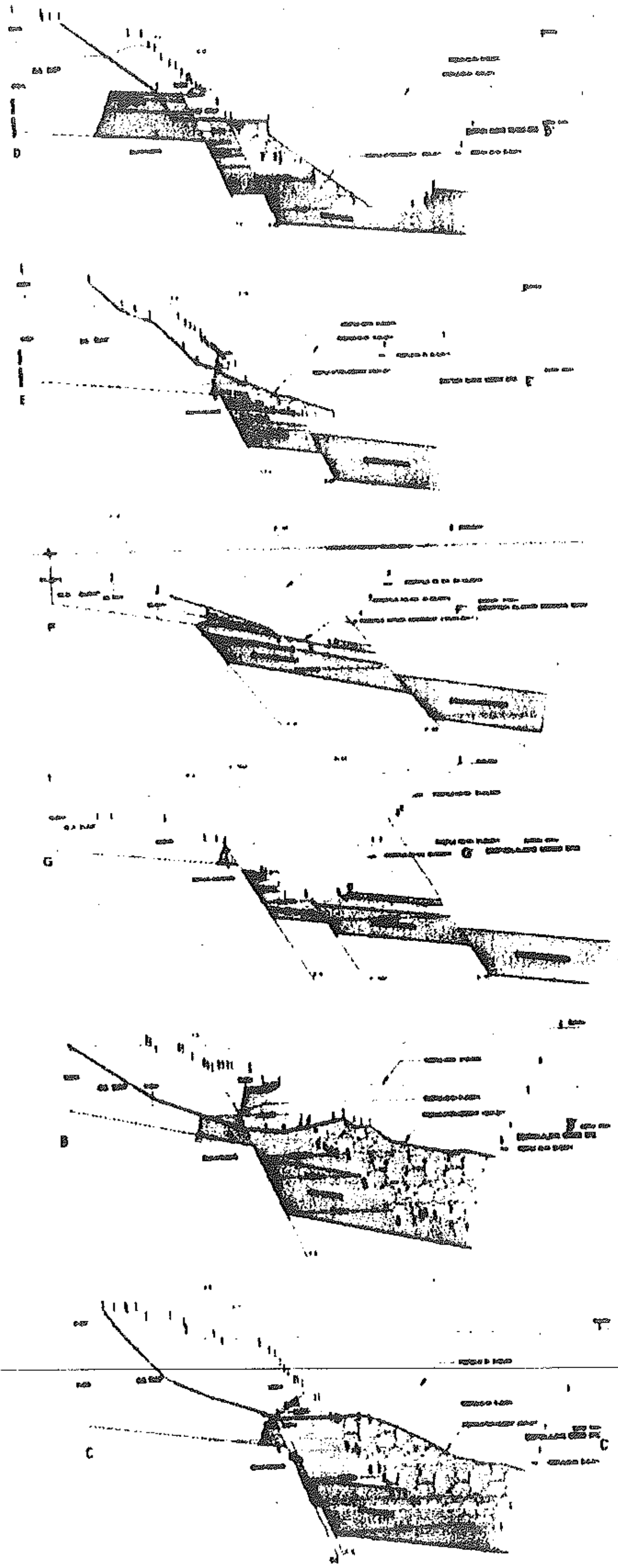


Figure 2: Mine plan of dump (Plan no ECL/RJML/OCP/DMZ/341 dated 04/05/2018)



(a) Section at 189100E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018)

(b) Section at 189200E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

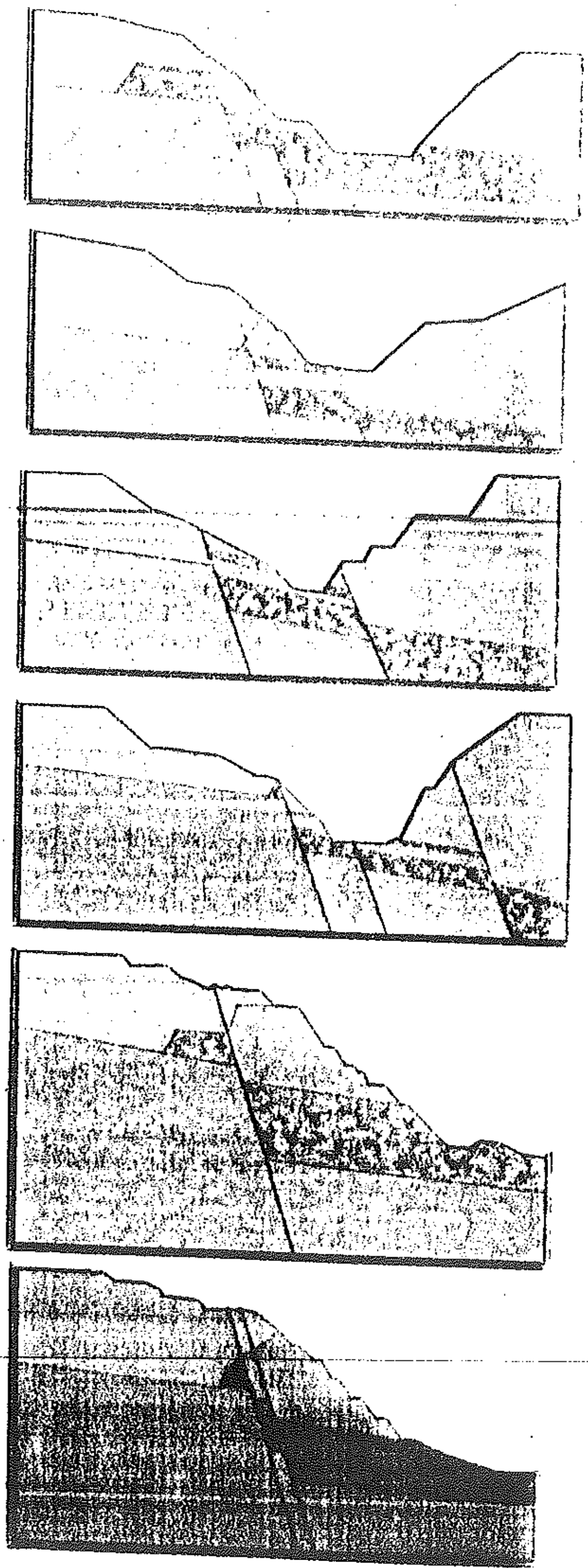
(c) Section at 189300E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

(d) Section at 189400E grid line (Plan no. ECL/RJML/OCP/DMZ/4 dated 04/05/2018))

(e) Section at 188900E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

(f) Section at 189000E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

Figure 3: Section of dump slope before failure



(a) Section at 189100E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018)

(b) Section at 189200E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

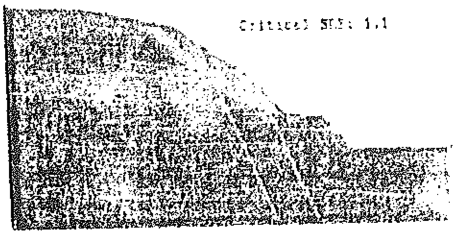
(c) Section at 189300E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

(d) Section at 189400E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

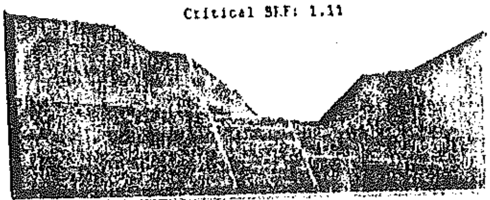
(e) Section at 188900E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

(f) Section at 189000E grid line (Plan no. ECL/RJML/OCP/DMZ/341 dated 04/05/2018))

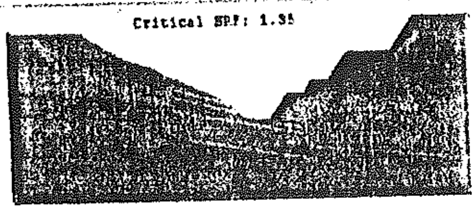
Figure 4:Descritized figure of dump slope before failure



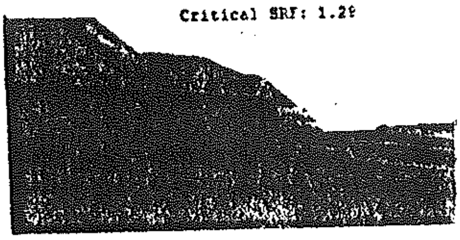
(a) Section at 189100E grid line
(Plan no. ECL/RJML/OCP/DMZ/341
dated 04/05/2018)
Factor of safety = 1.10



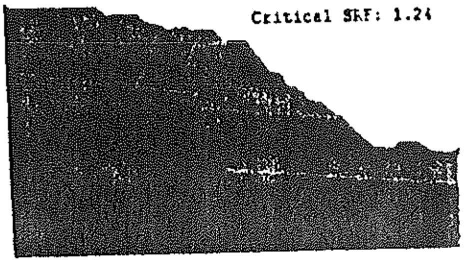
(b) Section at 189200E grid line
(Plan no. ECL/RJML/OCP/DMZ/341
dated 04/05/2018)
Factor of safety = 1.11



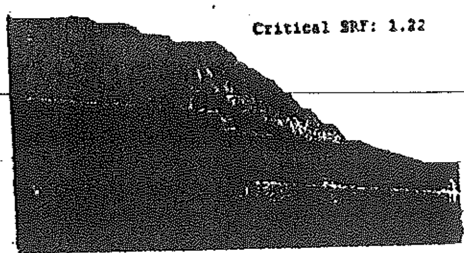
(c) Section at 189300E grid line
(Plan no. ECL/RJML/OCP/DMZ/341
dated 04/05/2018)
Factor of safety = 1.35



(d) Section at 189400E grid line
(Plan no. ECL/RJML/OCP/DMZ/341
dated 04/05/2018)
Factor of safety = 1.29



(e) Section at 188900E grid line
(Plan no. ECL/RJML/OCP/DMZ/341
dated 04/05/2018)
Factor of safety = 1.24



(f) Section at 189000E grid line
(Plan no. ECL/RJML/OCP/DMZ/341
dated 04/05/2018)
Factor of safety = 1.22

Figure 5 :Maximum Shear Strain with factor of safety before failure

Table 5: factor of safety of different sect[illegible] before failure

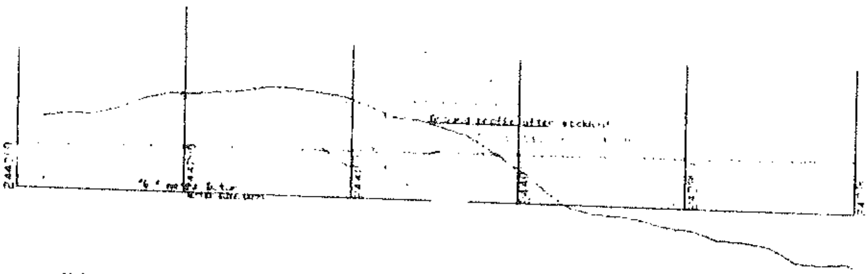
Sr. no	Sections	Factor of safety before failure
1	189100	1.10
2	189200	1.11
3	189300	1.35
4	189400	1.29
5	188900	1.24
6	189000	1.22

Figure 6-7 shows the various sections along the Mine dump for patch work and existing condition. These sections are used for the simulation of dump slope. The simulations have been done with the help of finite element method 'PHASE2' software and used for calculating the factor of safety of dump slope. Factor of safety has been calculated by strength reduction technique. The factor of safety includes a margin of safety to guard against ultimate failure, to avoid unacceptable deformations, and to cover uncertainties associated with the measurement of soil properties or the analysis used.

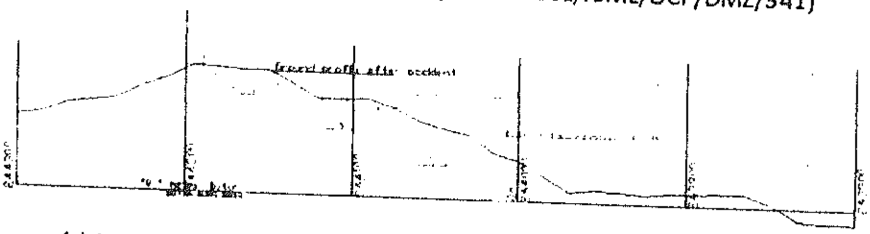
The figure 8 -9 show descritized view of dump slope by finite element method. The factor of safety has been calculated for patch work. The results in terms of maximum shear strain and factor of safety has been shown in figure 10 -11.

The factor of safety of current condition varied from 1.09 to 2.7. It indicates that the some of the section in dump slope is stable for short term. One can also observe that the failure is initiated mainly in failed dump material. The failed material has very less shear strength and modulus of elasticity therefore the displacement is high and that has leaded to crack generation in the dump material. It is recommended that overburden can be excavated from top to bottom and crack should be filled before rainy season.

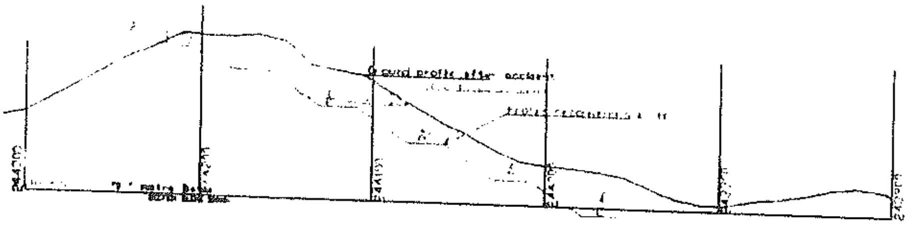
(a) Section along 189600E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



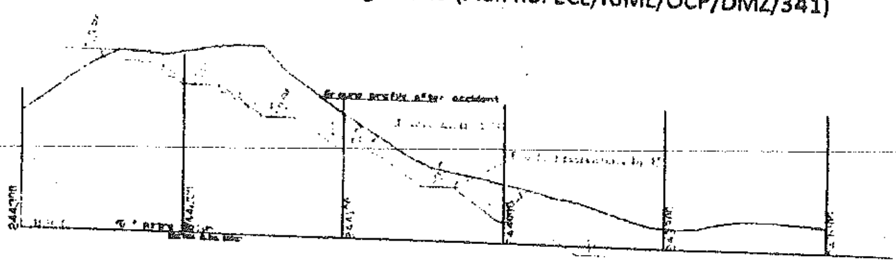
(b) Section along 188700E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



(c) Section along 188800E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

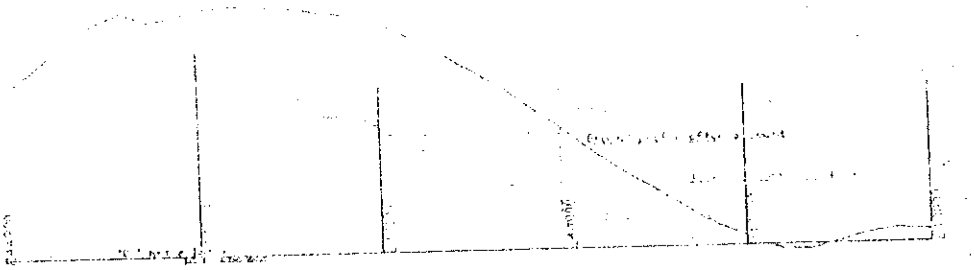


(d) Section along 188900E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

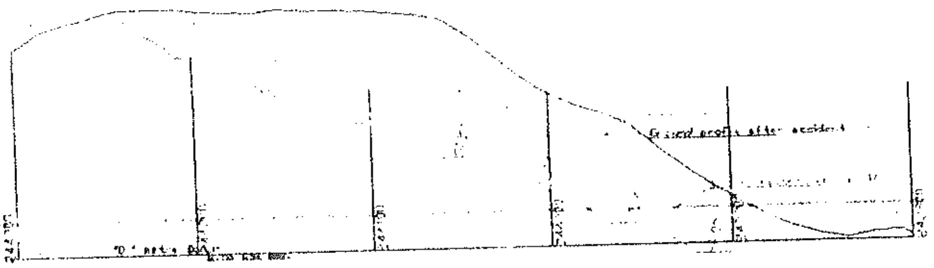


(e) Section along 189000E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

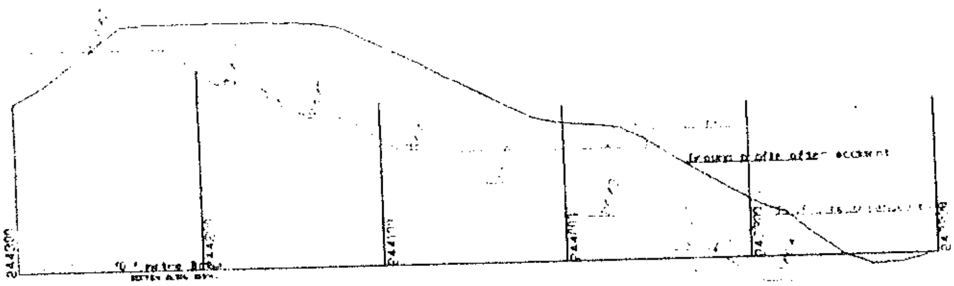
Figure 6(a, b, c ,d & e): Sections of patch work and present condition (Plan no ECL/RJML/OCP/DMZ/341 dated 04/05/2018)



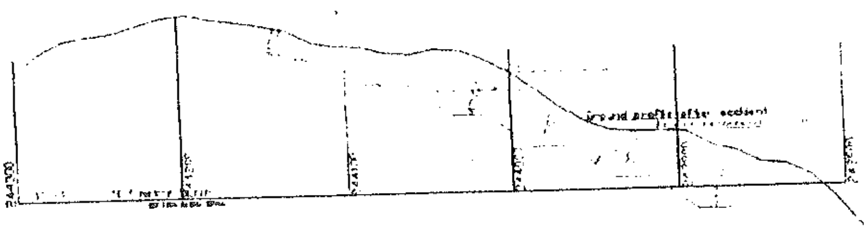
(f) Section along 189100E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



(g) Section along 189200E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

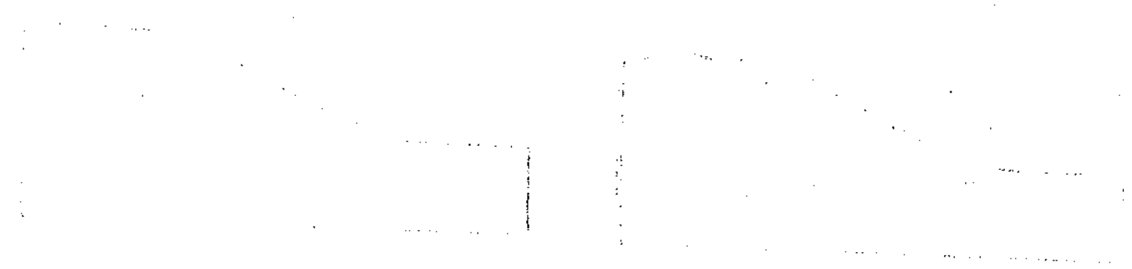


(h) Section along 189300E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

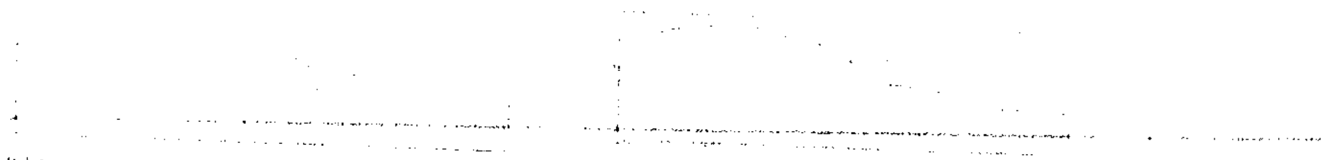


(i) Section along 189400E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

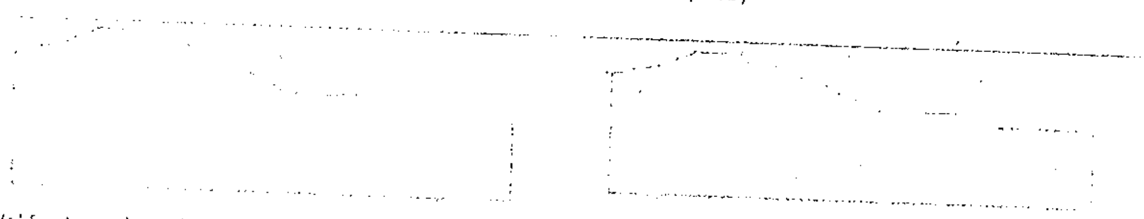
Figure 7 (f, g ,h & i): Sections of patch work and present condition (Plan no ECL/RJML/OCP/DMZ/341 dated 04/05/2018)



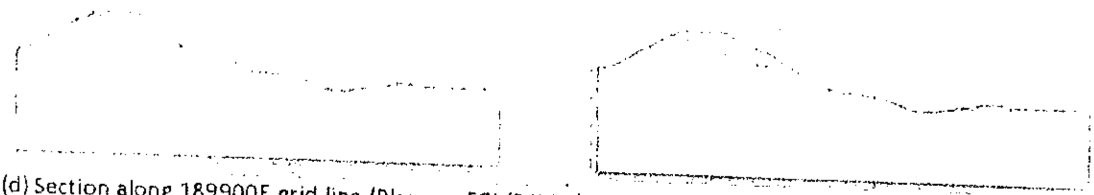
(a) Section along 189600E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



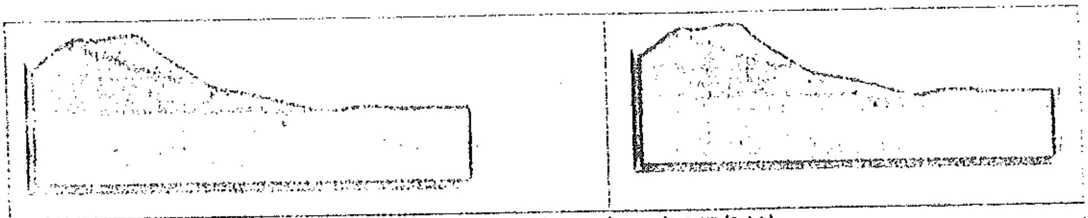
(b) Section along 189700E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



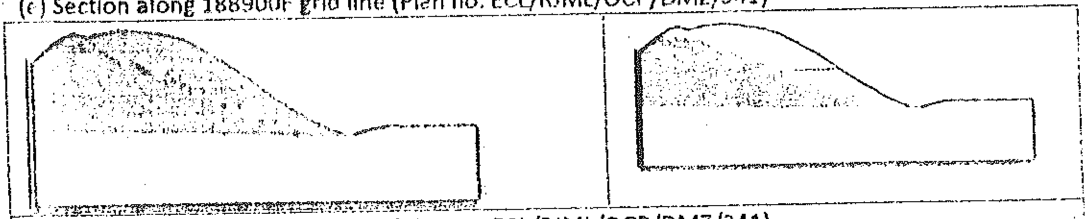
(c) Section along 189800E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



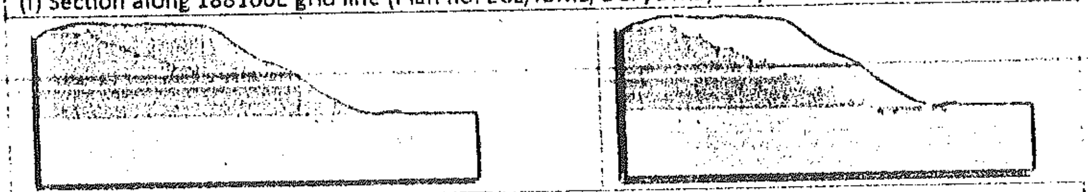
(d) Section along 189900E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



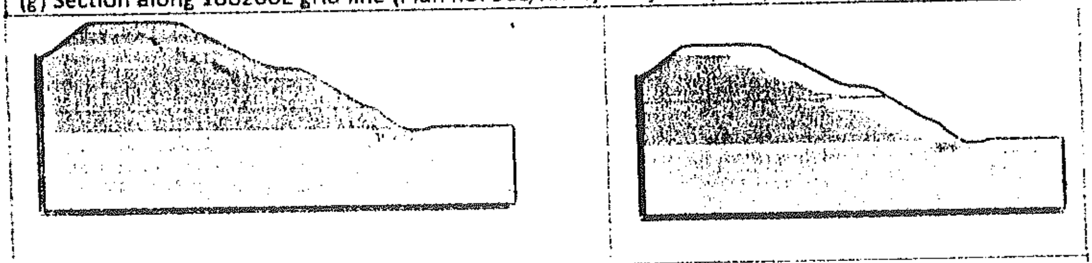
(e) Section along 188900E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



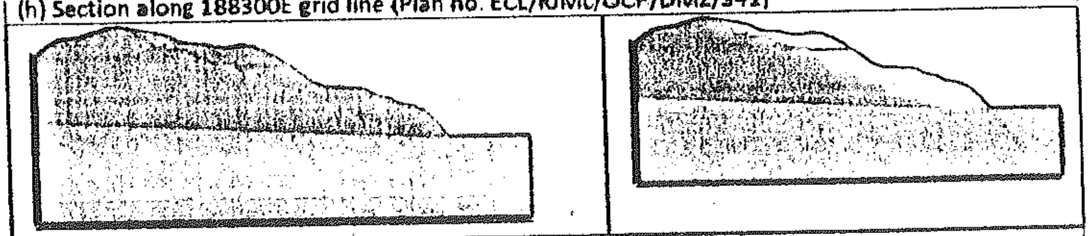
(f) Section along 188100E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



(g) Section along 188200E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

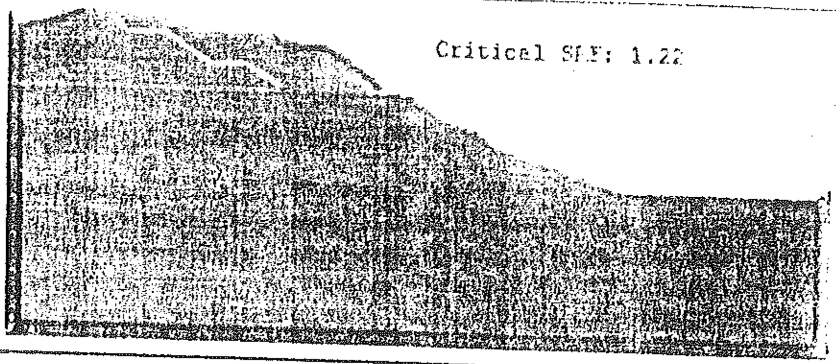


(h) Section along 188300E grid line (Plan no. ECL/RJML/OCP/DMZ/341)



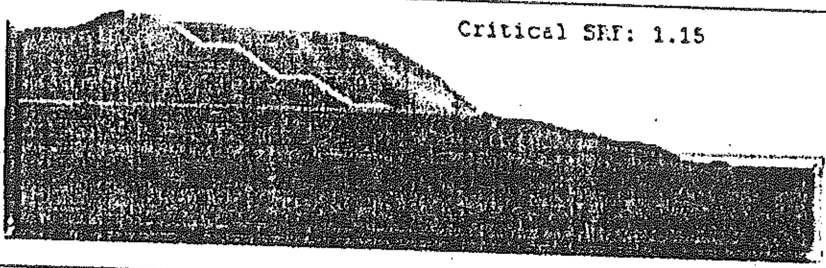
(i) Section along 188400E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

Figure 9 (e, f, g, h &i) :Descritized figure of dump material after failure, current condition and recommended by HPC (Plan no ECL/RJML/OCP/DMZ/341 dated 04/05/2018)



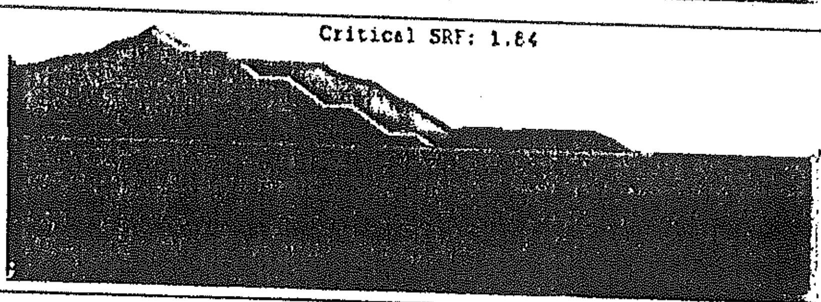
(a) Section 188600

Dump Height = 30 m
Bench slope angle = 57°
Overall Slope angle = 17°
Bench Height =3 m,
Bench Width = 9 m



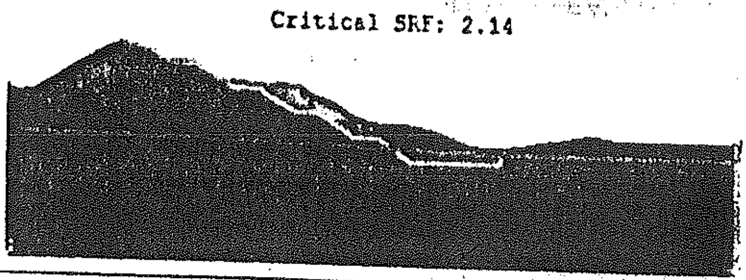
(b) Section 188700

Dump Height = 54 m
Bench slope angle = 57°
Overall Slope angle = 15°
Bench Height =3 m,
Bench Width = 9 m



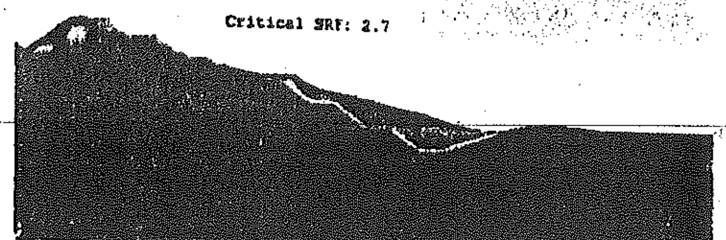
(c) Section 188800

Dump Height = 85 m
Bench slope angle = 57°
Overall Slope angle = 16°
Bench Height =3 m,
Bench Width = 9 m



(d) Section 188900

Dump Height = 84 m
Bench slope angle = 57°
Overall Slope angle = 16°
Bench Height =3 m,
Bench Width = 9 m



(e) Section 189000

Dump Height = 97 m
Bench slope angle = 57°
Overall Slope angle = 16°
Bench Height =3 m,
Bench Width = 9 m

Figure 10: Maximum Shear strain and factor of safety with detail of the models at present conditions (Plan no ECL/RJML/OCP/DMZ/341 dated 04/05/2018)

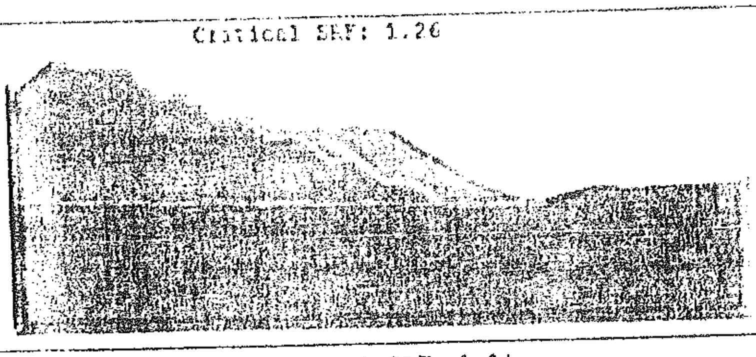
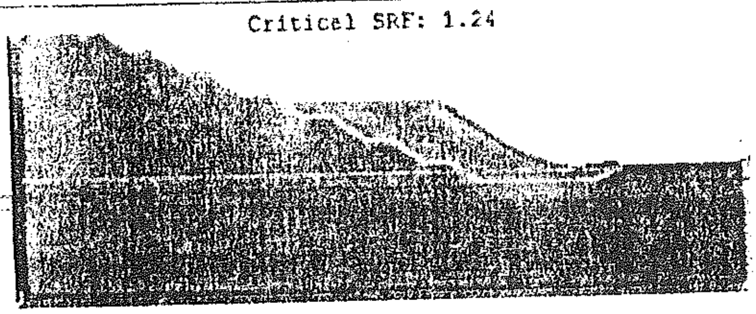
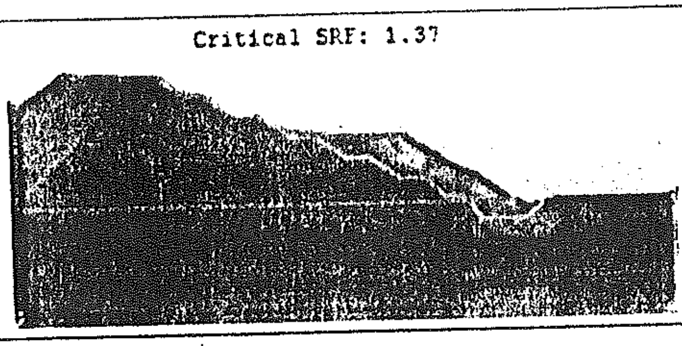
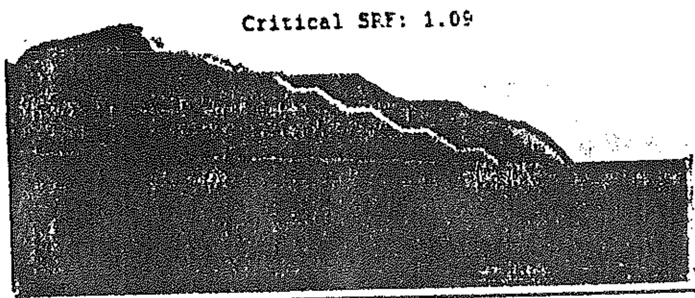
	(f) Section 189100 Dump Height = 117 m Bench slope angle = 57° Overall Slope angle = 16° Bench Height =3 m, Bench Width = 9 m
	(g) Section 189200 Dump Height = 124 m Bench slope angle = 57° Overall Slope angle = 16° Bench Height =3 m, Bench Width = 9 m
	(h) Section 189300 Dump Height = 124 m Bench slope angle = 57° Overall Slope angle = 16° Bench Height =3 m, Bench Width = 9 m
	(i) Section 189400 Dump Height = 120 m Bench slope angle = 57° Overall Slope angle = 14° Bench Height =3 m, Bench Width = 9 m

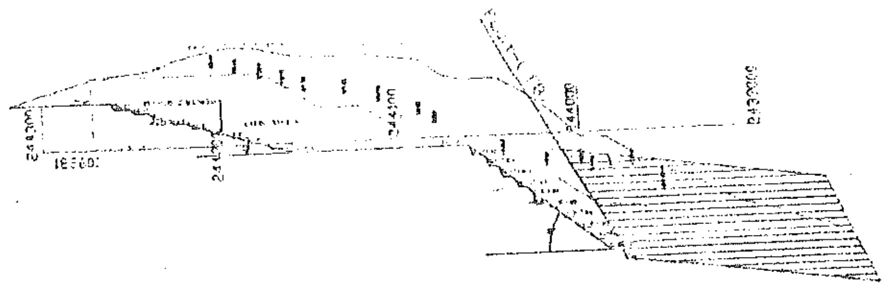
Figure 11: Maximum Shear strain and factor of safety with detail of the models present conditions (Plan no ECL/RJML/OCP/DMZ/341 dated 04/05/2018)

3.3 Simulation of final design

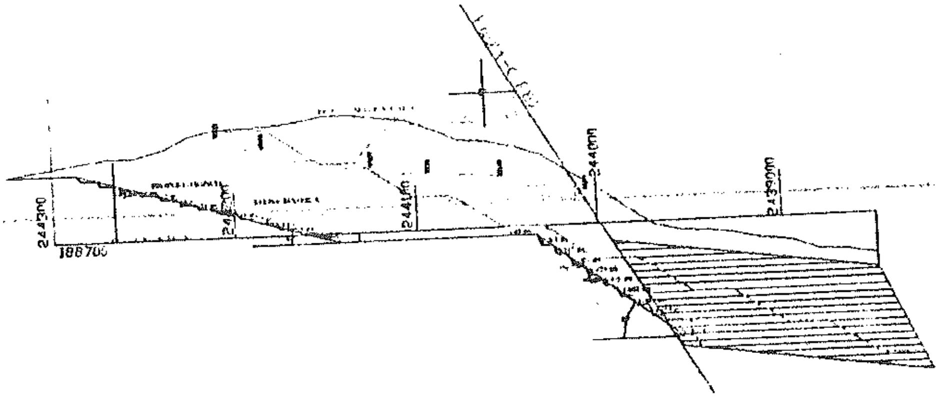
The design of final mine benches and slope profile is collected from the mine officials (Plan no ECL/RJML/OCP/DMZ/341 dated 04/05/2018). Nine sections have been taken for the detailed study for stability of dump on above plan. Figure 12-14 show dump profile at section 188600E, 188700E, 188800E, 188900E, 189000E, 189100E, 189200E, 189300E and189400E. The simulations have been done with the help of finite element method (figure 15). 'PHASE2' software has been used for calculating the factor of safety of dump slope.

The dump overburden material has been assumed to be placed in a loose state which will allow for any free water within the dump to drain out. Therefore, it has been considered that the dump foundation is horizontal and free-draining. Hence, a phreatic surface within the dump was not considered in the modelling of dump slope.

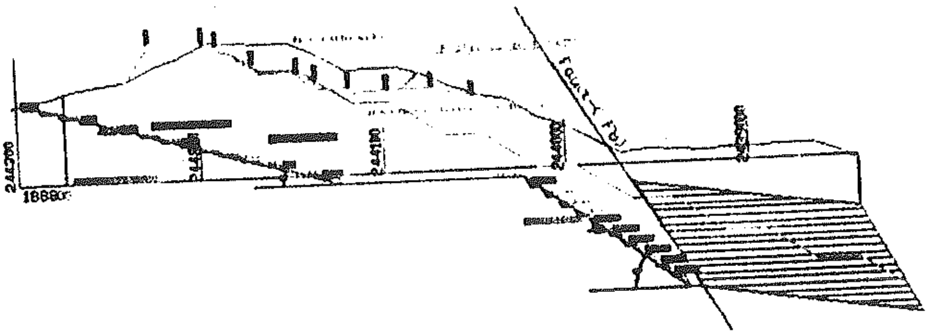
Material properties have been assigned to the model as given in table 3. The complete model is divided into two parts i.e. dump material, insitu rock. The results in terms of factor of safety have been tabulated (table 6) and maximum shear strain has also been plotted in figure 16. It is observed that the factor of safety is varying from 2.51 to 3.19. It indicates that the slopes are stable in long term.



(a) Section along 188600E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

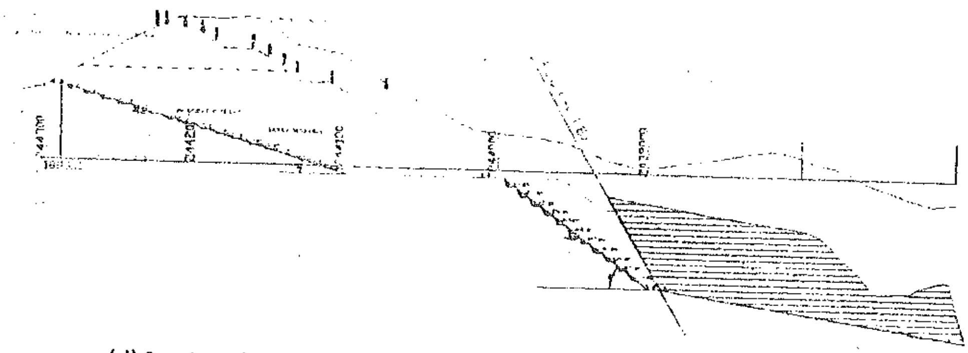


(b) Section along 188700E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

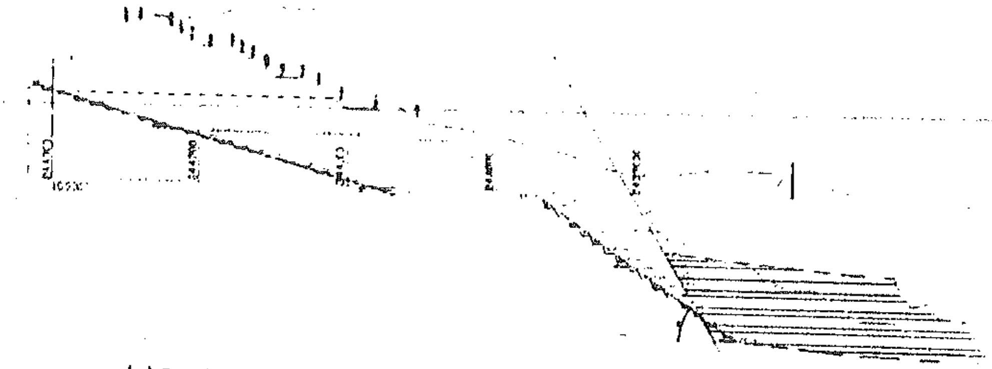


(c) Section along 18800E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

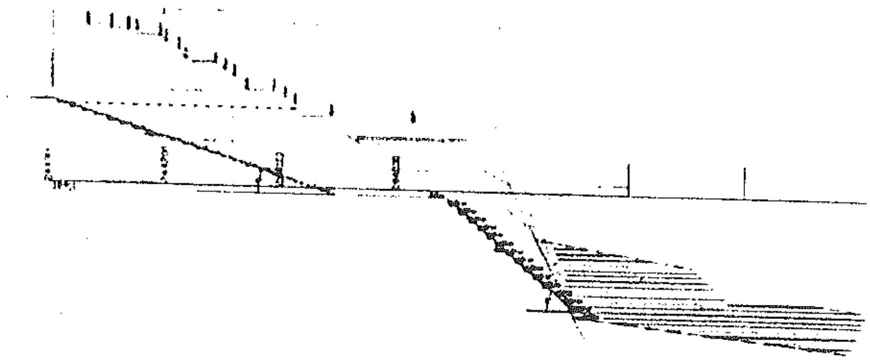
Figure 12 (a, b & c): Sections for final design



(d) Section along 188900E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

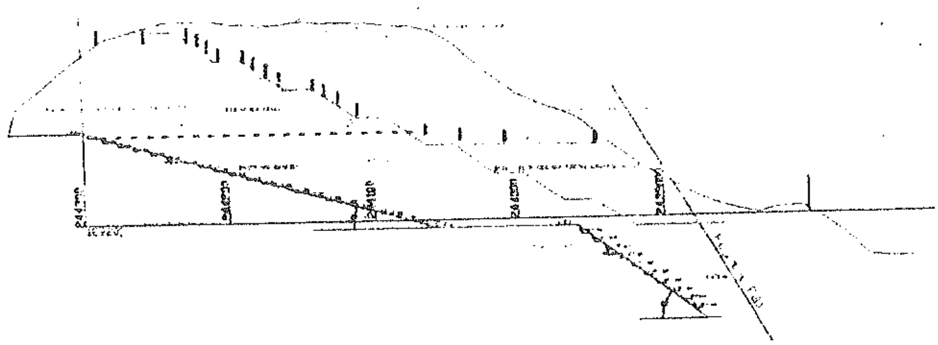


(e) Section along 189000E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

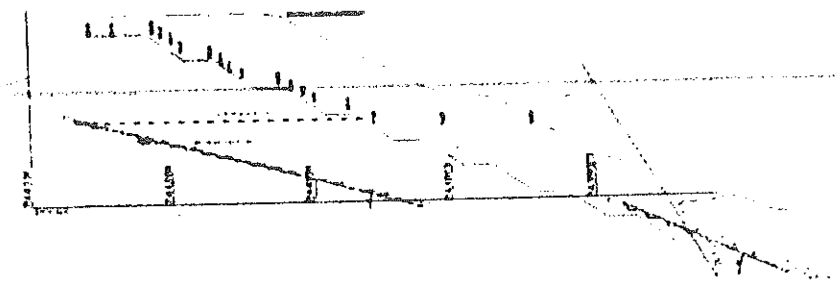


(f) Section along 189100E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

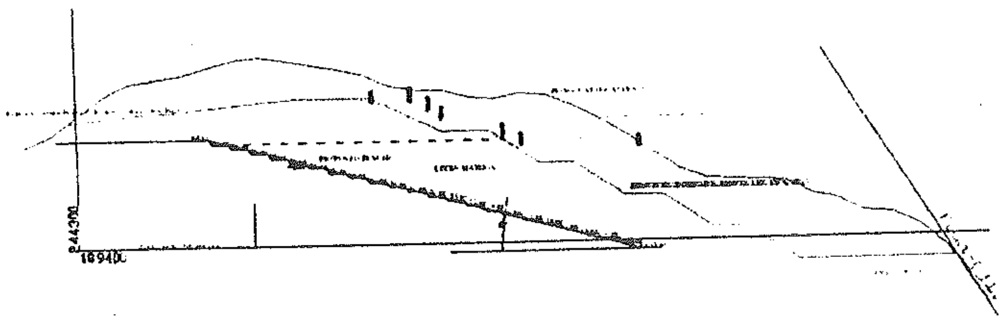
Figure 13(d, e & f): Section for final design



(g) Section along 189200E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

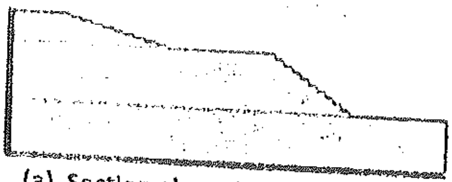


(h) Section along 189300E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

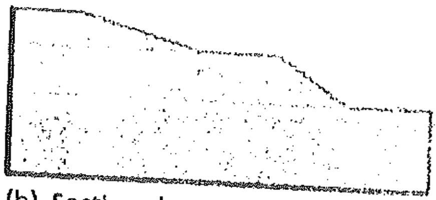


(i) Section along 189400E grid line (Plan no. ECL/RJML/OCP/DMZ/341)

Figure 14 (g, h & i): Section for final design

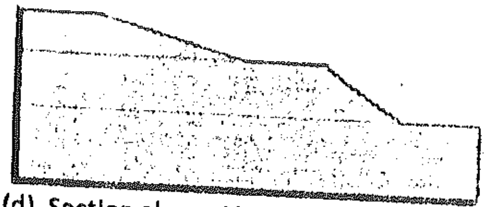


(a) Section along 188600E grid line

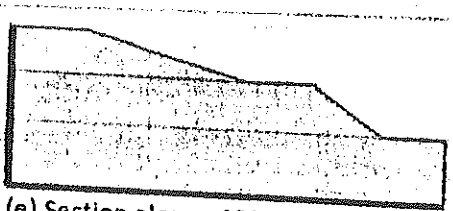


(b) Section along 188700E grid line

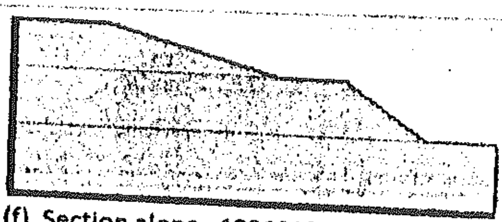
(c) Section along 188800E grid line



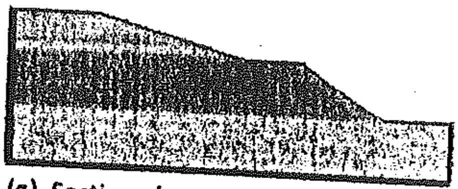
(d) Section along 188900E grid line



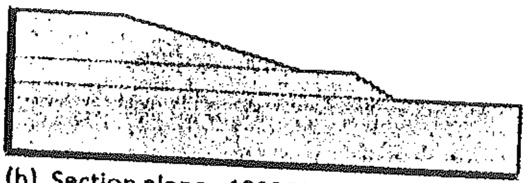
(e) Section along 189000E grid line



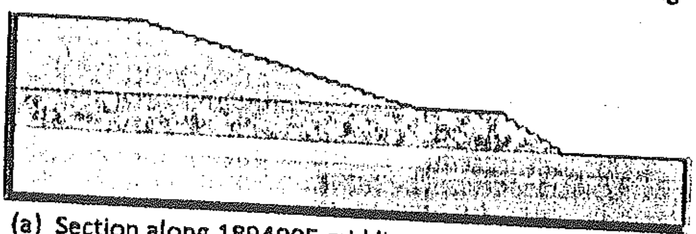
(f) Section along 189100E grid line



(g) Section along 189200E grid line

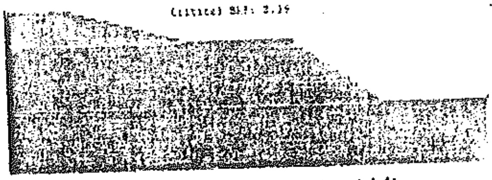


(h) Section along 189300E grid line

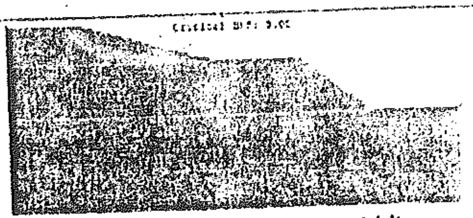


(a) Section along 189400E grid line

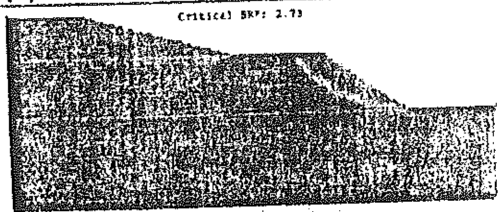
Figure 15: Descritised model of final design (Plan No ECL/RJML/OCP/DMZ/341 dated 04/05/2018)



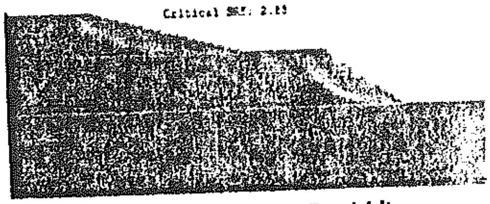
(a) Section along 188600E grid line



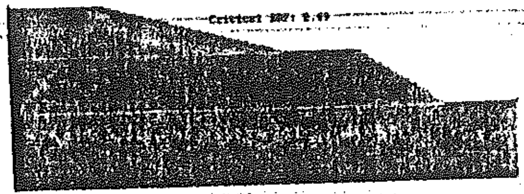
(b) Section along 188700E grid line



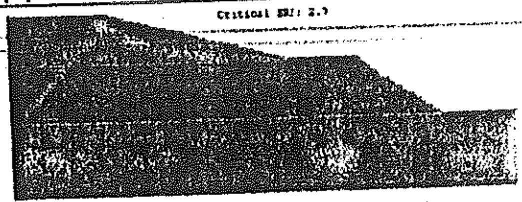
(c) Section along 188800E grid line



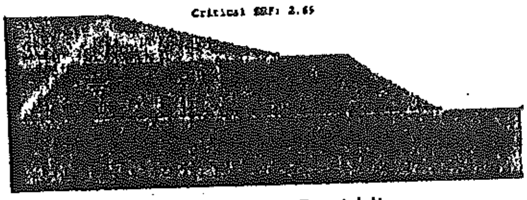
(d) Section along 188900E grid line



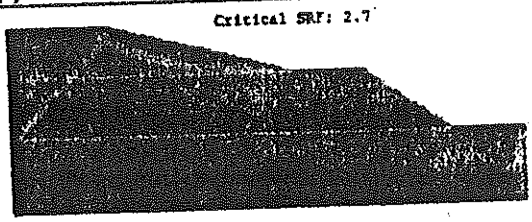
(e) Section along 189000E grid line



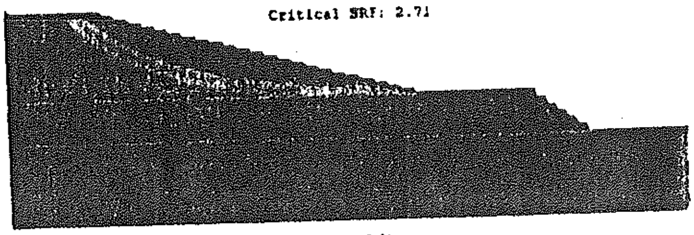
(f) Section along 189100E grid line



(g) Section along 189200E grid line



(h) Section along 189300E grid line



(i) Section along 189400E grid line

Figure 16 : Maximum Shear strain and factor of safety of the final design

Table 6: Details of the model of final design

Sr.	Model details for dump	Factor of Safety
1	**Section 188600** Dump Height = 30 m, Overall Slope angle = 17^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	3.19
2	**Section 188700** Dump Height = 42 m, Overall Slope angle = 16^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	3.08
3	**Section 188800** Dump Height = 48 m, Overall Slope angle = 16^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	2.73
4	**Section 188900** Dump Height = 54 m, Overall Slope angle = 16^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	2.83
5	**Section 189000** Dump Height = 69 m, Overall Slope angle = 16^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	2.71
6	**Section 189100** Dump Height = 70 m, Overall Slope angle = 16^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	2.72
7.	**Section 189200** Dump Height = 70 m, Overall Slope angle = 16^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	2.69
8.	**Section 189300** Dump Height = 70 m, Overall Slope angle = 16^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	2.78
9.	**Section 189400** Dump Height = 70 m, Overall Slope angle = 16^0 Bench slope angle = 58^0, Bench Height =3 m, Bench Width = 9 m	2.71

4.0 Conclusions

The stability for various sections of dump slopes in different conditions was carried out for Rajmahal Opencast mine. Finite element method has been used for analyzing the dump slope for different geo mining conditions. The factor of safety of 1.2 to 1.5 should be taken as short stability & Factor of safety > 1.5 for long term stability. However, due to previous accident in Rajmahal OCP and various uncertainties and discussion with competent authority and mine official, the Factor of safety more than 2.5 has been considered as long term stability for the present study. The present scenario is termed as patch work profile. The conclusions and suggestion of the present study are summarized below.

- The factor of safety of patch work is varied from 1.09 to 2.7. It indicates that some of the section of the dump slope is short term stable. One can also observe that the cracks has initiated mainly in failed dump material.
- It is recommended that one can excavate the material from top to bottom. The failed material has very less shear strength and modulus of elasticity therefore the displacement is high and that has lead to crack generation in the dump material.
- It is observed that the slope is short term stable only at some sections. Therefore, it is advisable that during rainy season the proper drainage system should be adopted and precaution should be taken for patch work.
- The final designs are provided by the mine officials in terms of nine sections. The factor of safety has been calculated for various sections. The factor of safety is varied from 2.51 to 2.82. It indicates that the dump slope is stable for long term
- Dump slope do not fail without warning and may be managed through design of dump sequencing, re-sloping of selected areas. Regular monitoring of dump slope is also being advised. It is recommended that a qualified person to ensure that the dumps are constructed as specified by the design drawings.

- The monitoring program should include visual inspection of the dump slope, specially crest, slope face and toe areas for evidence of cracking, seepage, erosion, deformation etc. It is recommended that these areas be visually inspected by the shift supervisor or field engineer. Other observations (cracking, seepage, erosion, deformation) should also be logged properly.
- It has been observed that some cracks are visible on the surface of the dump. All these cracks must be filled and light weight material should be filled before rainy season.
- Monitoring should be done daily for strata movement.

5.0 Final Recommendations

- It is being recommended that the work must be done in two phases.
- In phase one the excavation of overburden dump should be done from top to bottom (i.e.124 MRL to -5 MRL). The RL of top of existing OB Dump is 124 mtr. & the insitu rock mass is at -5 MRL. It will be completely de-capped from 124 MRL to 64 MRL approx. The direction of advancement of working will be rise to dip.
- Phase one is bounded by grid 188600E to 189500E and 243600N to 244350N demarcated by red colour in plan **no ECL/RJML/OCP/DMZ/341 dated 04/05/2018 (Annexure 1)**. It is being recommended that the maximum height of dump should be 70m from insitu ground (expeted MRL -5) with maximum overall slope angle 15 degree. The bench height should be of 3m and width should be 9m in dump material.
- At this -5MRL, a 100 meter clear space from toe of dump should be left in in-situ which has been shown in plan & section attached **(ECL/RJML/OCP/DMZ/341 dated 04/05/2018)**

- The phase two will only start after completion of phase 1. In-situ excavation will be done in phase two. Phase two is bounded by grid 188600E to 189500E and 243600N to 244100N demarcated by green colour in plan no ECL/RJML/OCP/DMZ/341 dated 04/05/2018(Annexure 1). The overall slope angle should be 27 degree during working in in-situ rock benches. It is being recommended that the final overall slope angle should be 37 degree with bench height of 6m and width of 6m in in-situ strata.
- The fault will be exposed and rock mass near the fault can be observed during the excavation in insitu. It is likely that the rock mass near the fault is disturbed. Therefore, it is recommended that the rock mass near the fault must be observed during the excavation. If the rock mass is disturbed near the fault then the design of bench in terms of height and width shall be freshly carried out based on scientific study.
- It is being recommended that the fault plane should be excavated and removed through benching. The material of footwall side of fault F8 should be removed during excavation of overburden or coal.
- The monitoring program include visual inspection of the dump slope, specially crest, slope face and toe areas for evidence of cracking, seepage, erosion, deformation etc. It is recommended that the shift supervisor or field engineer visually inspect these areas.

Other observations (cracking, seepage, erosion, deformation) should also be logged properly. Bench should have gradient in any direction for proper drainage.

- Continuous slope monitoring is essential to dete any instability in advance to safeguard against possible slope failure. The dump shall be regularly surveyed to produce up to date & accurate dump geometry.
- Adequate infrastructure to be provided for imparting training on slope stability to all concerned person employed in such large open cast mines.
- Technical competence of the contractual supervisors shall be appropriately scrutinized before deploying them in the mine.
- It is possible that any unfavourably oriented structural discontinuity (shear plane/fault/s) may be present in the mining area, which could not be detected during exploratory drilling and it is detected during ongoing excavation. It may create unsafe mining condition. The resident Geologist should conduct field mapping to see the existence of faults in the fresh exposure of the pit. It will help to detect the impending failure along these undetected weak planes.
- A few small-scale failures may subsequently cause a big failure. If two or three benches are made steeper at any level in any part/depth of the pit/dump then it may initiate failures. Although the overall slope angles may be quite low but the steeper slope angles of three benches may increase the stress at the toe of relatively steeper part of the slope, which may cause failures. Two or three such small failures may cause a big failure. So benching should be done properly from top to bottom.
- In case there are multiple fault planes, bench design should be such that they do not strike parallel to fault plane.
- Thus, it is strongly recommended to go for extensive monitoring of all the benches to detect any cracks development and its effect on the stability of benches.
- The monitoring stations should be installed at an interval of 50 meter on all benches in staggered manners so that effective gap between two stations of two immediate upper and lower benches would be 25 meters only.
- The Monitoring should be done daily for strata movement on daily basis. If there is detected any crack, deformation, movement in benches, it shall be immediately informed to higher management, if the symptoms are abnormal, it must be referred to ISO & DGMS

...d scientific agency and the work will be stopped till further instruction from Statutory bodies are obtained.

- **Implementation strategy**-- Mine management will comply all the recommendations as detailed above by IIT BHU in line with the plan & sections bearing no.ECL/RJML/OCP/DMZ/341 dated 04/05/2018.
- Further the working will be under the supervision of one Sr. Manager assisted by three under managers one in each relay/shift.
- Each shift under manager will be assisted by two supervisors. All of them will supervise the re-handing operation and ensure that ensure that working is done as per the recommendation & plan as mentioned above.
- The under manager/supervisors will inspect all the working area for dump slope, specially crest, slope face and toe areas for evidence of cracking, seepage, erosion, deformation etc. in the beginning of shift, middle of shift and end of the shift and hand over the charge to succeeding shift.
- One surveyor will ensure the supervision of strata movement by total station on daily basis by putting the target at every bench at a distance of 50meters in a staggered fashion.
- The mine manager will ensure every operation is being carried out as per the recommendations & plan and statutory provisions holistically.

Prof B K Shrivastva

(Principle Consultant)

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Deptt. of Mining Engg.
IIT (BHU), Varanasi-221005

Dr. Rajesh Rai

(Co-Consultant)
Associate Professor
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Varanasi-221005,UP

EASTERN COALFIELDS LIMITED
(A Subsidiary of Coal India Limited)
Office of the General Manager(P/C)
Rajmahal Group of Mines
PO –Bara Simra 814165
Godda, Jharkhand
Mail-Id: rajmahal.ecl@gmail.com

Ref No: ECL/RGOM/GM(P/C)/ 639

Date.21.04.2018

WORK ORDER

To,
Prof. B.K Shrivastva
Coordinator
Centre of Advanced Studies
Department of Mining Engineering
Indian Institute of Technology
(Banaras Hindu University)
Varanasi (UP) India
Phone 0542 2369434
Mobile: 09415222629.

Sub:- Work Order for " Scientific Studies of ultimate pit slope, dump slope and Monitoring Plan as per CMR 2017 for slope stability of total area of Dahernangi Patch, Rajmahal OCP

Ref. : Your Letter no. Min/BKS/2017-18/74 Dated 06.03.2018 (by mail).

Dear Sir,

The competent authority is pleased to award the subject work with following approved estimate of the job as agreed by you.

Sl.No.	Name of the Work	Amount(Rs.)
1.	"Scientific Study from grid value 188300E to 189600E and grid 243500N to 244300N (total area of Dahenangi Patch) for designing bench height, width and ultimate pit slope due to following circumstance:- 1. To comply with the provision of newly amended Regulation no. 106 of Coal Mines Regulation 2017. 2. After rescue recovery to extract coal on the down throw side of F8-F8 fault safely.	11,00,000.00
2.	GST 18%	1,98,000.00
Total		12,98,000.00

(Rupees Twelve lakhs ninety eight thousand only)

Cont. on page no. 2

-2-

Financial terms and conditions:-

1. Paying authority - Area Finance Manager, Rajmahal Area
2. Payment - Payment will be made through RTGS within five days in advance
   Bank Name - State Bank of India, IT-BHU Branch, Varanasi - 221005
   IFSC Code - SBIN0011445
   Bank Account No. 34923598941, Bank Account Name – R & D
3. Company shall not have liability whatsoever on any account except for paying for the work done and admitted by the Company of the accepted awarded rate.
4. Time of completion is 90 days from the date of issue of the work order. Try to complete the study at the earliest possible.

The Work Order is being issued to you in duplicate. You are requested to send one copy of the work order to this office duly signed by you as a token of your acceptance.

This issue with the approval of the competent authority.

Yours faithfully

General Manager (I/C)
Rajmahal Area

BC No. ECL/RJML/Rev./18-19/OCW(Safety)/004226/01 dt. 21.04.2018 for Rs. 12,98,000.00
(Rupees Twelve lakhs ninety eight thousand only)

Copy to:
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